JOURNAL
OF THE
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OCTOBER 1927

PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

MEETINGS

of the

American Institute of Electrical Engineers

(See Announcements This Issue)

REGIONAL MEETING, Great Lakes District, Chicago, November 28, 29 and 30

WINTER CONVENTION, New York, N. Y., February 13 to 17, inclusive

MEETINGS OF OTHER SOCIETIES

Illuminating Engineering Society, Edgewater Beach Hotel, Chicago, October 11-14

National Electric Light Association

Rocky Mountain Division, Colorado Springs, October 17-20

Kansas Section, Salina, Kan., October 20-21

Institute of Radio Engineers (Joint Meeting) New York, N. Y., October 17

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

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Election of Officers of the A. I. E. E.

The actions specified in the Institute's Constitution and By-laws relative to the organization of a National Nominating Committee are being taken, and the meeting of the National Nominating Committee for the nomination of officers to be voted upon at the election in the Spring of 1928 will be held between November 15 and December 15. All suggestions for the consideration of the National Nominating Committee must be received by the Secretary of the Committee at Institute Headquarters, New York, not later than November 15.

The sections of the Constitution and By-laws governing these matters are quoted below:

CONSTITUTION

28. There shall be constituted each year a National Nominating Committee consisting of one representative of each geographical district, elected by its Executive Committee, and other members chosen by and from the Board of Directors not exceeding in number the number of geographical districts; all to be selected when and as provided in the By-laws; The National Secretary of the INSTITUTE shall be the secretary of the National Nominating Committee, without voting power.

29. The executive committee of each geographical district shall act as a nominating committee of the candidate for election as vice-president of that district, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The National Nominating Committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The National Nominating Committee shall name on or before December 15 of each year, one or more candidates for president, treasurer and the proper number of managers, and shall include in its ticket such candidates for Vice-Presidents as have been named by the nominating committees of the respective geographical districts, if received by the National Nominating Committee when and as provided in the By-laws; otherwise the National Nominating Committee shall nominate one or more candidates for vice-president(s) from the district(s) concerned.

BY-LAWS

SEC. 21. During September of each year, the Secretary of the National Nominating Committee shall notify the chairman of the executive committee of each geographical district that by November 1st of that year the executive committee of each district must select a member of that district to serve as a member of the National Nominating Committee and shall, by November 1st, notify the secretary of the National Nominating Committee of the name of the member selected.

During September of each year, the Secretary of the National Nominating Committee shall notify the chairman of the executive committee of each geographical district in which there is or will be during the year a vacancy in the office of vice-president, that by November 15th of that year a nomination for a vice-president from that district, made by the district executive committee, must be in the hands of the Secretary of the National Nominating Committee.

Between October 1st and November 15th of each year, the Board of Directors shall choose five of its members to serve on the National Nominating Committee and shall notify the secretary of that committee of the names so selected, and shall also notify the five members selected.

The Secretary of the National Nominating Committee shall give the fifteen members so selected not less than ten days' notice of the first meeting of the committee, which shall be held not later than December 15th. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the National Nominating Committee must be received by the secretary of the committee by November 15th. The nominations as made by the National Nominating Committee shall be published in the January issue of the A. I. E. E. JOURNAL, or otherwise mailed to the INSTITUTE membership during the month of January.

F. L. HUTCHINSON,
National Secretary

Some Leaders of the A I. E. E.

Cummings C. Chesney, president of the Institute 1926-1927—and in May 1927 elected one of three new vice-presidents of the General Electric Company,—was born at Selingsgrove, Pennsylvania, October 28, 1863. He graduated from the Pennsylvania State College in 1885 and for three years thereafter taught mathematics and chemistry. In 1888 Mr. Chesney was employed by the William Stanley Laboratory at Great Barrington, Mass., where he devoted the major portion of his time specifically to experimental chemistry and electrodynamics. In 1889 he removed, with the Stanley Laboratory, to the plant of the U. S. Electric Lighting Co., subsidiary of the Westinghouse Electric & Mfg. Co., Newark, N. J. The following year, he and Mr. Stanley returned to Pittsfield, Mass., and organized the Stanley Electric Manufacturing Company, for the development of alternating-current equipment. Many of the subsequent developments in this line were made possible by Mr. Chesney's own inventions, and his company was responsible for the well-known S. K. C. (Stanley, Kelley, Chesney) system, which was the first of its kind in America to be put into successful operation in a polyphase transmission plant. One, although installed in 1893, is still supplying light and power to the towns of Housatonic and Great Barrington, Mass. In 1895, a 12,000-volt plant was installed for service between Lowell, Mich. and Grand Rapids, and here again the operating success of the alternators was due to the specially designed equipment by which

the high-voltage was generated in the stator element by a revolving rotor. This was the first production of a true sine wave voltage. At an early period, two-phase a-c. induction motors, electrostatic condensers for 500 volts and transformers of 100-light capacity were developed. In the transformer, all spaces in the coil were filled with Gilsenite to provide for better insulation and heat dissipation. The most effective general insulation in use today was developed by the Stanley Company 1891-1892, superseding the old insulating method of coating with shellac and P & B paint.

In 1893, the belt-driven alternator was successfully applied and in 1899, alternators of this design, direct-connected to steam engines, were used with excellent results in the power house of the Staten Island Electric Company. They were the first alternators to operate in parallel and to be put in regular commercial service. Switchboard instruments, high-voltage arc-breaking devices, frequency indicators, indicating wattmeters, lightning protectors for low- and high-voltage circuits, condensers, etc., were among much of other equipment produced by the Stanley Manufacturing Company; in fact this company built the first revolving field type of alternators used in America. These were extensively applied to large operations upon the Pacific Coast—the longest high-voltage lines then in any section of the world—using from 40,000 to 60,000 volts. Of his company, Mr. Chesney was vice-president and chief engineer from 1904 to 1906, when he was chosen chief engineer and manager of the Pittsfield works of the General Electric Company by which the Stanley Manufacturing Company was absorbed. Under Mr. Chesney's supervision, the Pittsfield works of the General Electric Company displayed remarkable progress in the development of apparatus for commercial service up to 1,000,000 volts. He was a tireless worker and made it a point at all times to keep in close contact with every phase of the organization's work. Many of the industry's highest honors have justly fallen to him, as well as awards for purely scientific achievement. In February 1922 he received the Edison Medal and a diploma in recognition of his contribution to the field of applied electricity and the perfection of a-c. machinery and high-voltage transmission. Prior to his term as president, he had served the Institute as manager (1905-1908) and as vice-president (1908-1910). He is a member of the Society of Arts, London, the American Society for the Advancement of Science and the Engineers Club of New York. Mr. Chesney has also done much for humanity as chairman of the industrial committee of the crippled children's home in Pittsfield, one of the best equipped industrial rehabilitation schools for children in New England. He is a director of the Agricultural Bank and president of the Morris Plan Bank of Pittsfield.

Wear Resistance of Gages Studied

Special tests by the United States Bureau of Standards to determine the wear of metal used in gages have been carried on with considerable difficulty because of the wear resistance of different metals and on account of many variables encountered in shop gaging practise. It has likewise been exceedingly difficult to secure data which would adequately define the conditions under which test gages might have been used.

One of the experts at the Bureau recently described a laboratory wear tester designed for plug gages. This machine which provides for the repeated insertion and removal of plug gages representing the "work" has been found to give consistant results because of the possibility of closely controlling the gaging conditions.

Supplementary and more extended tests have been made in which test gages were used without abrasives, in steel, aluminum alloy and cast iron containing appreciable proportions of pearlite showing that chromium steel gages had the highest resistance to wear. Ammonia treated chromium alluminum steel was next. These were stated to be vastly superior to the remainder of the group. In general file soft steel showed better resistance to wear than corresponding steel in the file hard condition. This difference was most noticeable in an oil hardening tool steel.

Machinery Versus Man Power

In spite of the great increase in population since 1914, the factories of the United States are employing seven per cent less men, due to the wide spread use of machinery, according to Secretary of Labor, Davis. Restrictive immigration has made it possible to carry these great developments without hardships according to the Secretary and "in the end every device that lightens human toil and increases production is a boon to humanity. It is only the period of adjustment when machines turn workers out of their old jobs into new ones, that we must learn to handle them so as to reduce distress to the minimum.

"Every day sees the perfection of some new mechanical miracle that enables one man to do better and more quickly what many men used to do. In the past six years especially, our progress in the lavish use of power and in harnessing that power to high-speed productive machinery has been tremendous. Nothing like it has ever been seen on earth. But what is all this machinery doing for us? What is it doing to us? I think the time is ripe for us to pause and inquire."

The Secretary then reviews several industries in which machinery has made possible a marked reduction in labor.

Abridgment of

Transients Due to Short Circuits

A Study of Tests Made on the Southern California Edison 220-Kv. System

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Synopsis.*—The paper deals with records which have been obtained during short circuits upon the Southern California Edison's 220-kv. system. The main features of the system are outlined, and such operating data as are necessary to afford an understanding of the various conditions which have to be met are included. The general scheme of relays is described, and the causes of flashovers and their times of occurrence are tabulated, together with the percentages which cause interruptions to service. Whether or not interruption is caused is found to depend, among other things, upon the load being carried at the time. With load below 150,000 kw., there are no interruptions unless relays are inoperative. A number of typical records of short circuits are shown and analyzed. It is shown that large amounts of power are consumed in short circuits, but that this is dependent upon the ground resistance. Practically all short circuits are single-phase to ground. The advantage of low-reactance machines is discussed and the various factors that prevent loss of synchronism pointed out. The records show that there is but little if any tendency for synchronous machines at either end of the line to fall out of step among themselves as a group, but that the sending end under certain conditions will get out of step with the receiving end.*

Introduction

THE ever increasing necessity of transmitting greater power over longer distances at higher voltages has led to considerable study during the last few years of the factors affecting the power limits of transmission systems. The ability of such a system to withstand short circuits without experiencing more than momentary disturbance is of the greatest importance in determining its economic capacity rating. The problem was first attacked by theoretical analysis, concentrating upon the steady state or static limits. Supplementary shop tests were made, in so far as a power system could be duplicated in miniature, but assurance was still lacking, that the results obtained would apply to actual systems.

Subsequent analysis and observation of power systems indicated that their behavior during transients, such as those caused by short circuits and switching, was of the greatest importance. A very large amount of theoretical work was done in connection with this phase of the problem and an extensive series of tests was made upon the Pit River system of the Pacific Gas and Electric Co. The results of this work are described in two papers before the Institute[3]. The close agreement between the results of the test and calculations indicated that any specific condition on a given system can be analyzed mathematically with a reasonable degree of accuracy, and the system designed accordingly. However, to obtain the over-all performance of a system, it is necessary to know not only its performance under stated conditions but also the character and frequency with which such conditions will be met in practise.

The Southern California Edison Company's Big Creek lines have been operated at 220 kv. since May 6, 1923. Prior to that time, no automatic relaying of sections of the line was in use. Since relays have been in operation, the larger percentage of faults have been cleared without interruption to service; some of the short circuits occurring at times of heavy load have caused the two ends of the system to go out of step even after proper elimination of a faulty section of line by relays. This has happened also as a result of heavy short circuits on 60-kv. lines out of 220-kv. substations.

In order to obtain information as to just what happened on this system under these abnormal conditions, special recording instruments were furnished by the Westinghouse Company and installed at a number of points upon the system. By their use, data as to the type of trouble and its effect upon the system have been recorded.

The purpose of this paper is to present the results of this investigation, which has been going on since August, 1925. Although the details of the disturbances encountered will undoubtedly be different on other systems in different localities, yet there will be points in common, and the range of conditions to be met will probably be of at least the same order on all systems, and the analysis be of more than local application.

The single-line diagram of the Big Creek system, Fig. 1, shows the unit system (220-kv.) at each station.

220-Kv. Relay System

Since the 220-kv. transmission system of the Southern California Edison Company is the backbone of the entire system, the importance of perfect automatic sectionalizing is supreme. Statistics show that approx-

1. Southern California Edison Company, Los Angeles, Calif.
2. Westinghouse Electric & Mfg. Company, E. Pittsburgh, Pa.

3. *Studies of Transmission Stability*, by R. D. Evans and C. F. Wagner. *Practical Aspects of System Stability*, by Roy Wilkins, A. I. E. E. Trans., Vol. 45, p. 41.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Calif., Sept. 13-16, 1927. Complete copies available upon request.

imately all failures on the 220-kv. lines are one phase to ground. Therefore the most important protection on these lines is the ground fault protection. Since faults must be cleared in a very short time to prevent interruption, a scheme that is not extremely fast in operation should not be used.

Many relay schemes were devised and tried out on actual dummy systems. The one that proved most successful was the current balanced relays for phase-to-phase and phase-to-ground faults. All the Big Creek plants,—Vestal, Magunden north, Eagle Rock, Gould south and Laguna Bell—are equipped with two-line phase and ground balance current relays.

In the case of trouble on the last or single line in any section, ordinarily the arc can be broken only by lowering the voltage of the system. This is done by actuating a time relay by means of ground current at all the Big Creek generating and 220-kv. substations, which, in some cases, trips the voltage regulator, and in others, starts a motor-driven rheostat to lower the exciter voltage of the generators and condensers.

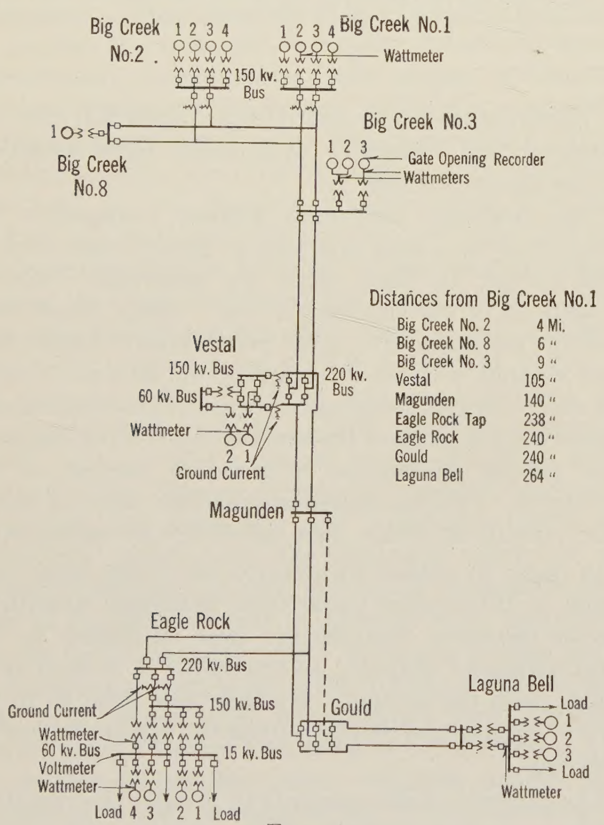

Fig. 1

Time and Causes of Flashovers

The total number of flashovers on the 220-kv. lines from January 1, 1924 to May 1, 1927, occurring during the various hours of the day is shown by Curve A, Fig. 7. Curve B is an average daily load curve for one year. It will be seen that most of the flashovers have occurred between the hours of 3 a. m. to 7 a. m., during the light load period. Line C, indicating the load below which flashover does not cause outage, shows correct relay operation and will be discussed later. (Refer also to Fig. 8.)

Restoration of Service

Ordinarily when a section of line is cleared by relays, the service is not interrupted. Some times with heavy loads, however, the shock to the system is too great and the Big Creek end and the receiving end fall

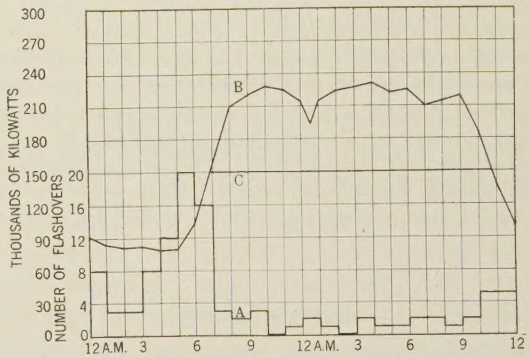

Fig. 7

out of step with each other. In this case, the steam plant picks up as much load as possible and the Big Creek plants try to hold normal speed. In the meantime, sufficient load is dropped, accidentally or otherwise, so that the plants can pull up the load to normal speed. Normally this may take from one minute up to several.

When a flashover occurs on a non-automatic section of line, the flashover suppressors lower the voltage and as soon as the arc breaks bring the voltage up. The devices are timed to make this complete operation in 15 sec. Sometimes, at heavily loaded periods, the driving force at Big Creek pulls out of step with the rest of the system by over speeding. The system is

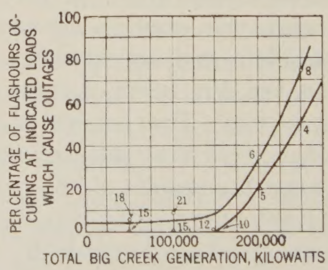

Fig. 8

brought back together in a similar way as above but usually takes a little longer.

System Outage

The proportion of times the system is likely to be put out of service due to flashovers is variable, depending upon the load, system connections, and the severity of the trouble.

Fig. 8 is a chart showing what the percentage of outages has been due to 220-kv. flashovers occurring at

different loads. Curve A shows this relation in which outages from all causes are included. In Curve B, only those cases in which perfect relay action was secured are included. The difference between the two curves is principally accounted for by incorrect relay operation and operation with relays not in service.

It will be seen that for loads below approximately 150,000 kw., the probability of outage is very small and has been zero when the relay operation has been perfect. The Line C in Fig. 7 has therefore been drawn to this value. By reference to the load and flashover curves of Fig. 7, it will be noted that during the period in which loads in excess of 150,000 kw. are transmitted, the number of flashovers is small resulting in few actual outages. For this reason, the system can economically be operated at a high rating without serious possibility of outage.

The 220-kv. system has been caused to fall out of step due to troubles originating on the 60-kv. lines, the relation between the percentage of outage and transmitted load being similar, in a general way, to the curve shown by Fig. 8. It has been found that by setting the relays on the 60-kv. system adjacent to Eagle Rock and Laguna Bell for short time tripping, the communication of these troubles to the 220-kv. system has been very greatly reduced.

Recording Apparatus

The instruments used during these tests were not designed for continuous operation, but were arranged to be cut into service whenever a ground current flowed on the 220-kv. system, due to a line-to-ground fault. The general plan of the initiating equipment an automatic recording instrument control, is shown in Fig. 9. An induction type relay, A, is connected to operate whenever current flows in the neutral of the main transformer bank at the station. This relay is set so as to operate in about one-tenth second with an average value of ground current. Its contacts complete the circuits of several auxiliary relays, which connect the different elements of the recording apparatus into circuit. The contacts of one of these auxiliary relays parallel the initiating relay contacts, locking the circuit so that the instruments continue to operate even though the fault current has ceased. After a period of about 25 sec., another relay, B, short-circuits the holding coil of the lock-in relay, causing it to open and disconnect the apparatus. Wherever possible, the required power was taken from a source independent of the main system, so that the instruments would continue to operate even though there was a service interruption.

The various quantities measured are as follows:

1. Power into or out of station
2. Ground current
3. Bus voltage
4. Hydraulic gate opening.

The installations were made at a number of remotely separated points on the system in order to record the changes taking place at different parts of the system, and also to insure getting at least one record for each disturbance. This was rendered necessary because a short circuit at one end of the system did not always give a sufficiently large current at the other end of the system to operate a ground current relay.

Typical Records

During the period in which the automatic recording apparatus has been installed, records have been obtained on about 65 flashovers. Of these, no two are exactly alike, since they involve different system set-ups, different loads, and different type and location of fault. Consequently from the large number of records available, it has been necessary to select a few which may be taken as typical of the different conditions that may ocur in practise. The total synchronous kilo-volt-amperes listed refer to the capacity connected at Big Creek, Vestal, Eagle Rock and Laguna Bell.

At the time this flashover took place, there was no

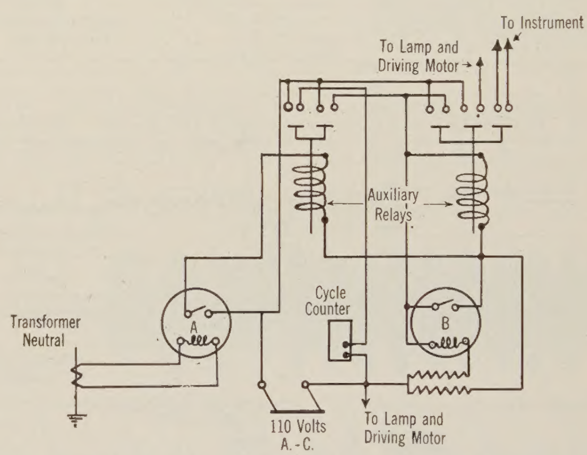

Fig. 9

automatic protection in case a short circuit occurred on the 150-kv. bus, except that provided by the operation of the flashover suppressors; consequently the short circuit continued for several minutes. The records were taken at Big Creek No. 3, and show the combined output of generators No. 1 and No. 2, the output of, and hydraulic input to generator No. 3. The first two seconds of the record is omitted since there was little variation during this period. At about three seconds after the beginning of the short circuit, the power output at Big Creek No. 3 begins to fluctuate slightly, the rapidity of the fluctuations gradually increasing. This is probably due to the generators at Big Creek No. 1 pulling out of step with the rest of the system owing to the reduction in their field currents by the action of the flashover suppressors. After having thus pulled out of step, the mean output of Big Creek No. 1 is very small, and the loss of this generating capacity allows the system as a whole to drop in frequency. This causes the governors at

Big Creek No. 3 in an attempt to regain normal frequency, to open up as shown by the record of gate opening of the No. 3 unit. Meanwhile, the arc suppressors at Big Creek No. 3 have also functioned, making the generators in that plant incapable of sustaining their load, and they also pull out of step, as evidenced by the rapid reversals of power. Each reversal in the direction of power flow means that the generators at Big Creek No. 3 have slipped a pole with respect to the rest of the system, and that they are overspeeding. The hydraulic input to the generators is then decreased by the action of the governor until normal frequency is regained. The remainder of the charts, (not shown in the illustration), shows the clearing of the short circuit and subsequent building up of load. During this period, there was considerable hunting of the governors.

This flashover, Fig. 15, occurred at a time when the transmitted load was fairly high, and, in addition, the fault resistance was of such a value as to cause a large amount of power to be consumed. This combination of circumstances was such as to cause loss of synchronism despite the fact that the line was relayed out correctly. The oscillographs from both Eagle Rock and Vestal showed that the generators had commenced to pull out of step within three-fourths second after the beginning of the flashover. (The first visible cycle on the oscillograms taken at Eagle Rock and Vestal are about 20 cycles after the start of the short circuit due to the time lag of the relays and the oscillograph lamp.) The variation in magnitude of the ground current is due to the change in voltage as the Big Creek machines shift in phase position with reference to each other and to the remainder of the system. The first visible part of the record shows that the ground current first decreases and then pulsates in amplitude indicating that the phase position of the Big Creek machines has advanced beyond the point corresponding to the maximum power limit. The enormous amount of energy consumed by this flashover is shown by the records from Laguna Bell and Eagle Rock. While the short circuit lasted (about 1.5 sec.), the power fed out of the Laguna Bell substation was over 90,000 kw., (this is the maximum the instrument could record in this direction), while the

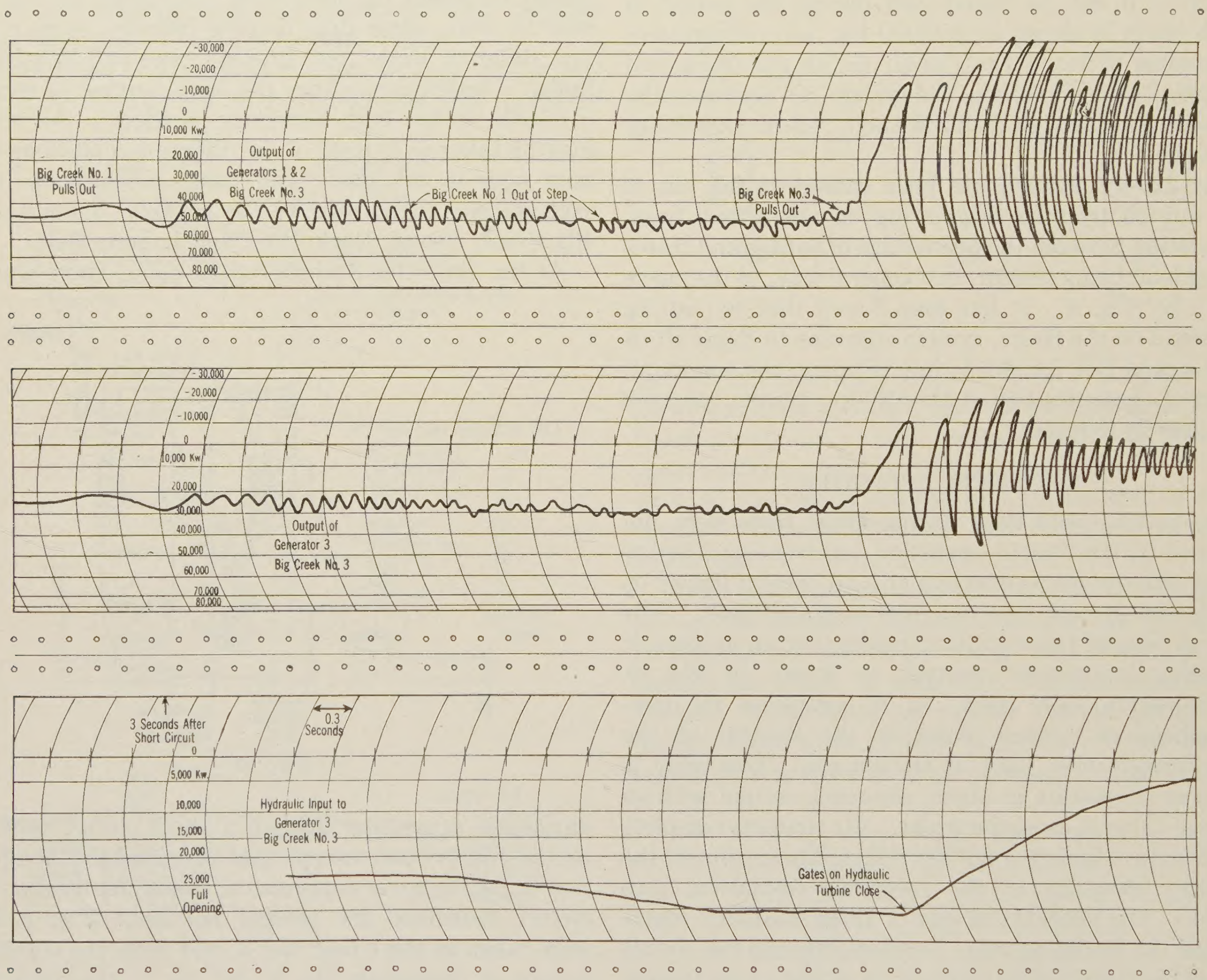

Fig. 10—(September 3, 1925). Flashover on 150-Kv. Bus at Big Creek No. 1. Big Creek Generation, 201,000 kw. Total Synchronous Kilovolt-Ampere, 424,000

amount of power originally fed into this substation was 74,000 kw., a difference of over 164,000 kw. The original amount of power into the Eagle Rock substation was 120,000 kw., dropping to 30,000 kw. when the flashover struck. Therefore the total Big Creek power to the two receiving stations changed from 194,000 kw. in, to 60,000 kw. out, when the flashover occurred, a difference of 254,000 kw. No record was obtained of the corresponding variation in Big Creek power, but it is probable that it dropped somewhat momentarily owing to the comparatively low resistance of the fault and the high reactance of the 233-mi. of line.

The amplitude of voltage at the Eagle Rock substation varies at the slip frequency, as shown by the oscillogram. The fact that the fluctuations in synchronous condenser power occur at this same frequency shows that the condensers are maintaining synchronism with the bus to which they are connected, and are not, themselves, out of step. No instances have been recorded in which synchronous condensers have gone out of step with the station bus voltage.

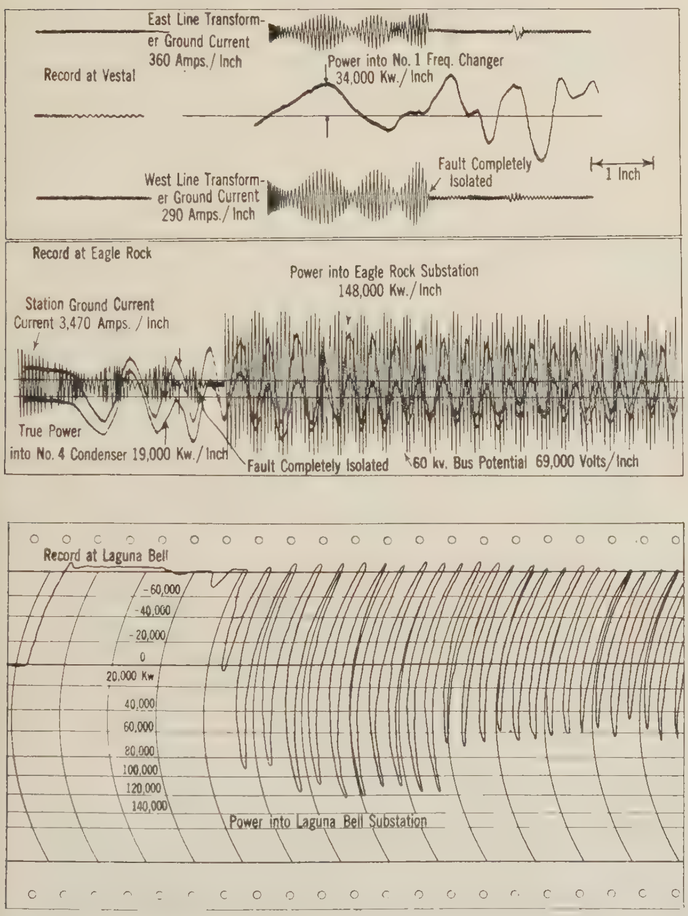

FIG. 15—(DECEMBER 9, 1926.) 220-KV. FLASHOVER AT MILE 233. TOTAL BIG CREEK GENERATION, 192,000 KW. TOTAL SYNCHRONOUS KV-A., 457,500

Fig. 16 shows oscillograms typical of those obtained where the system does not pull out of step with a 220-kv. flashover. The drop in voltage is very slight even while the short circuit is on, and it immediately regains its original value after the short circuit is cleared. Except for this slight drop in voltage and small power surges, there is no system disturbance. The oscillogram taken at Eagle Rock furnishes a good illustration of the successive opening of circuit breakers as shown by the changes in ground current. Owing to the line connections employed, it is necessary for the breakers at three points to open to clear a fault in the section where the flashover occurred, increasing the total time required before the fault could be entirely cleared.

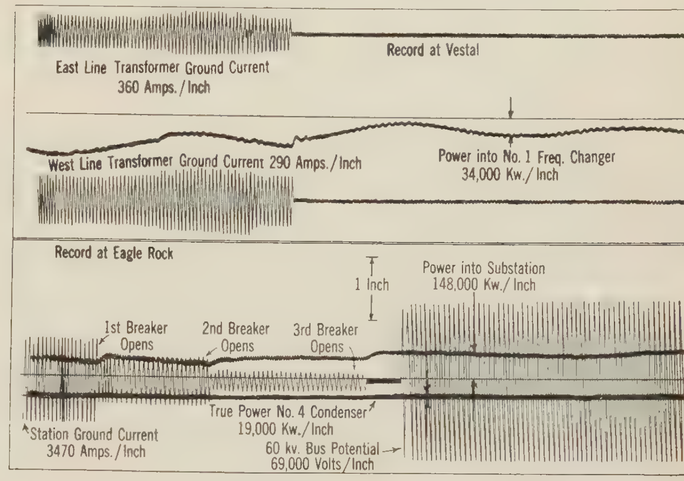

FIG. 16—(NOVEMBER 30, 1926). 220-KV. FLASHOVER AT MILE 238. TOTAL BIG CREEK GENERATION, 78,000 KW. TOTAL SYNCHRONOUS KV-A., 364,000

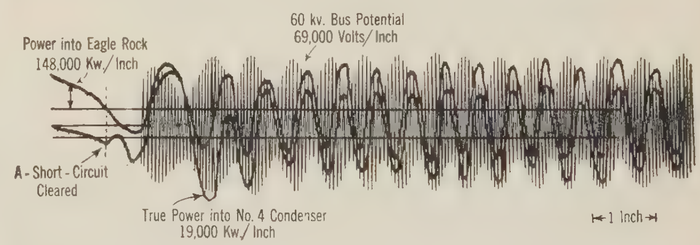

FIG 17—(JULY 31, 1926). 60-KV. SHORT CIRCUIT NEAR EAGLE ROCK. TOTAL BIG CREEK GENERATION, 205,000 KW. TOTAL SYNCHRONOUS KV-A., 439,500.

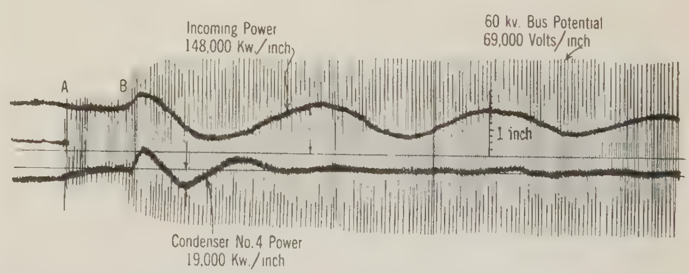

FIG. 18—(FEBRUARY 15, 1827). 60-KV. SHORT CIRCUIT NEAR MCNEIL SUBSTATION. TOTAL BIG CREEK GENERATION, 127,000 KW.

Fig. 18 gives a record included for the purpose of showing the type of the disturbance caused by a 60-kv. short circuit near McNeil substation, not resulting in loss of synchronism. The voltage on the 60-kv. bus dropped appreciably while the short

circuit was on, but quickly regained its normal value with very slight fluctuations accompanied by a surging of power from the Big Creek system. The breaker on the end of the line nearest to Eagle Rock probably opened at point A, reducing the ground current required below that to hold the initiating relay closed. The measurement of the 60-kv. bus potential starts at this time, the voltage being about half of normal until the short circuit is completely cleared at B.

Discussion of Individual Factors Affecting Stability

Out of a total of 65 disturbances taking place during the period that automatic recording apparatus was installed, there were practically no cases in which the system set-ups were identical or in which character of faults were the same. Consequently, it is not possible to make a direct comparison of some of the factors without the use of a certain amount of supplementary theory to place the cases on a common basis. The purpose of the following section is to isolate some of the factors affecting stability, and to analyze them individually, drawing upon the test results as much as possible.

Type of Faults

The 220-kv. disturbances occurring between August, 1925, and May, 1927, are as follows:

220-kv. line to ground	59
Station bus to ground	4
Conductor-break	1
Open discount	1
	65

These faults occurred in almost every possible combination. They included high-resistance faults at many points on the 220-kv. lines, low-resistance faults on the 150-kv. buses at the ends of the line, and occurred at times of widely varying loads; also, the operations have included those in which normal relay protection was in service and other cases in which the lines for maintenance work or otherwise were operated non-automatically. As shown by the tabulation, all but two of the faults were single-phase short circuits to ground, the protection for which should be made the basis of design. In this connection, it should be pointed out that although very few records were obtained from faults on the 60-kv. network, the number of faults on this network exceed those on the 220-kv. system. With the initiating relay scheme used, only the 60-kv. faults near the Eagle Rock substation were recorded. So far as the stability of operation of the 220-kv. system is concerned, only the 60-kv. faults occurring close to the Eagle Rock or Laguna Bell Substations are of importance. For these reasons, most of the subsequent discussion will be devoted to line-to-ground faults on the 220-kv. lines, and those line-to-ground faults on the 60-kv. system, close to the receiving substations.

Location of Faults

The location of a fault affects the stability of the system in two ways: (1) According to the amount of synchronous equipment and load in proximity to the fault, and (2), in so far as the local conditions affect the resistance of the fault. In order to evaluate the effect of the first, a set of curves was calculated to show the theorectical variation in the voltage, current, and power relation for faults of different resistance and locations. These curves were based on two-line operation with a single-phase ground on one line. A representative system condition was approximated by taking an average capacity in generators at the two ends of the line. Certain simplifying assumptions were made to facilitate calculations, the resistance of the lines and station ground being neglected and the generator voltages being assumed equal and in phase. The curves

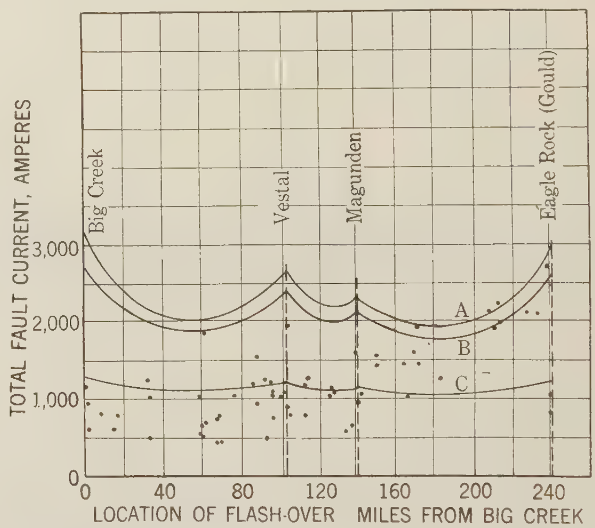

Fig. 19—Variation in Fault Current with Phase-to-Ground Flashovers at Different Locations

A—Zero fault resistance
B—25 Ohms fault resistance
C—100 Ohms fault resistance

of Fig. 19 show the variation in total fault current against location of fault for different fault resistances. With zero fault resistance, the current varies from about 2000 amperes in the middle of a section, to about 3000 amperes at either end. As the assumed resistance of the fault is increased, the variation due to location becomes less marked until, with 100 ohms resistance, the magnitude of the current is practically independent of the location. In order to get an approximate idea of the range of fault resistances actually encountered in practise, the values of total fault current obtained for different flashovers are plotted on this diagram. Graphic recording ground ammeters are used in all of the 220-kv. generating and substations, and the sum of the readings of these ammeters was used to indicate the total fault current. The values thus obtained are not very accurate, since the ammeters were not of a type

suitable for accurate measurement when the current was of short duration, and because the arithmetical rather than the vector sum was obtained. However, for purposes of comparison, it is believed that the figures are sufficiently reliable, particularly, since, with so many readings to be added, the individual errors would tend to cancel out. By comparing the observed and calculated values, it will be noted that the actual fault resistance varies from about 25 to 250 ohms. The lower values of fault resistance are found near the region of the receiving end of the system, and the higher values toward the sending end. This difference can be explained by the character of the country through which the transmission lines pass.

Fault Resistance

As indicated by the Curves of Fig. 19, the fault current is determined very largely by the fault resistance when it is above approximately 25 ohms. The relation between the curves and the points obtained from

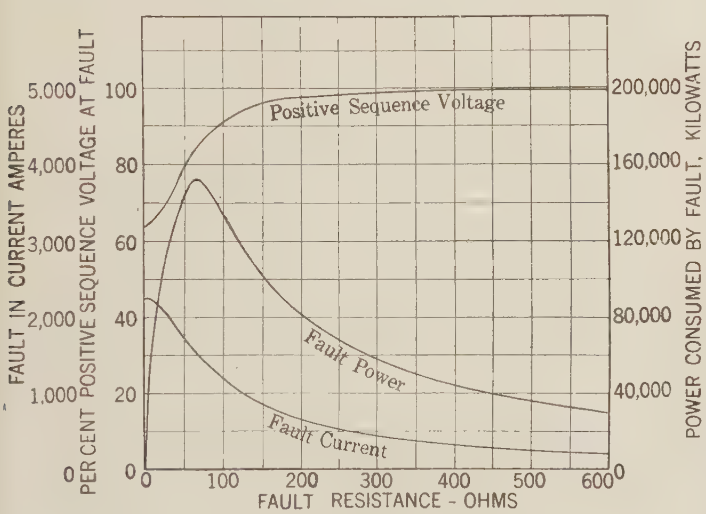

Fig. 21

ground current ammeter readings indicate that the fault resistances vary considerably, ranging from about 25 to 250 ohms. This value of ground resistance is very important in its effect on the system, as is shown by Fig. 21 which gives the different fault resistances for phase-to-ground fault at Magunden substation. The two most important quantities from the standpoint of stability are the reduction in voltage and the increase in power demand caused by the short circuits. Between 0 and 50 ohms, the positive sequence voltage varies from 64 per cent to 80 per cent, while the power demand varies from 0 to 150,000 kw. These curves were calculated for a short circuit at Magunden, and this range of resistance is the most critical for this point. Between 50 and 100 ohms ground resistance, the power demand due to the short circuit is practically unchanged, while the positive sequence voltage rises from 80 to 92 per cent. Although the results to the system are not so severe within this range as at the lower resistances, it is also rather a critical one, owing to the high power demand. Beyond 100 ohms, the power demand falls off rapidly, while the positive sequence voltage remains at a high value, resulting in the least shock to the system. For short circuits at other locations, the maximum power demand would be considerably increased The commercial load on the system is also changed by the short circuits, depending upon the drop in voltage and its duration.

The enormous amount of power consumed by a single phase ground is well brought out by the record from Laguna Bell shown by Fig. 15. In this case, the power taken by the fault was sufficiently great to change the power flow at the receiving substations from 194,000 kw. flowing in, to over 60,000 kw. flowing out. Assuming that the Big Creek power momentarily dropped by about 50,000 kw., due to the lower voltage at the receiver end, the indications are that about 200,000 kw. was consumed in the fault. When it is recalled that the total ground current during this flashover was over 2000 amperes, it will be seen that a fault resistance of only 50 ohms is necessary to account for the power in question. The effect of this load, suddenly thrown on and then suddenly released, was sufficient to cause the system to lose synchronism.

It should be noted that the conditions on the 220-kv. lines of the Southern California Edison Company are very favorable from the standpoint of fault resistance, since the very great majority are over 100 ohms in resistance, while the resistances which would cause the most disturbance are considerably lower in value. This fact should be borne in mind when estimating the probable performance of other systems by comparison, because if the fault resistances are low, poor operation may result even though the system is otherwise well laid out.

Owing to the great importance of ground resistance in determining the action of the system, it may in some cases be desirable to take special precautions to keep the resistance above the critical value by using high resistance overhead ground wires, resistance grounding of transformer neutrals with full, 220-kv., class insulation or some other method; whichever may be found to be most practical in any particular case.

Since no definite time of circuit breaker opening will be satisfactory for all cases, the best procedure is to obtain, as quickly as possible, an isolation of the fault. With the balance current type of relay used, it is possible to secure very rapid relay action, the minimum time being principally determined by the time required for the circuit breaker to open after being tripped. Oscillographic measurements during a large number of flashovers give the following average times from the beginning of the short circuit for operation of circuit breakers. Straight line sections, (two breakers to completely isolate line), 0.75 sec. for first breaker to open; 1.2 sec. for last breaker. Tapped line, (three breakers to completely isolate line), 0.75 sec. for first

breaker, 1.3 sec. for second breaker, and 1.7 sec. for last breaker.

Length of Line Sections

Owing to the fact that other conditions had a greater effect, it is not possible to show from the records the influence of the length of line section on stability of operation. Other things being equal, however, it is probably safe to assume that the length of the section affects the working power limit of the line about inversely as the percentage increase in the total system impedance, (including generator and transformer reactance), caused by switching out the section.

Reactance of Transformers and Machines

Owing to their nature, the tests could not show the value of low reactance in increasing the power limit of the system, but this point has been very well established by theory, and extensions of the system are being equipped with generators and transformers having reactances lower than the usual values.

60-kv. Short Circuits

On the Edison system, it has been the experience that short circuits on the 60-kv. network may be quite as detrimental to the operation of the 220-kv. lines as short circuits on the 220-kv. lines themselves if they occur close to the 220-kv. terminal substations. Fundamentally, short circuits close to terminal substations should differ but little in their effect upon the system whether they are on the 60-kv. or 220-kv. networks. Such differences as may actually exist must be due to conditions affecting the kilowatt and kilovolt-ampere demand on the system, and the duration. As pointed out in a previous section, the resistance of the majority of the faults on the 220-kv. lines is above the critical range owing to the character of the country through which these lines pass. On the 60-kv. network, the critical range of resistance is considerably lower, (approximately the ratio of the squares of the two voltages), but these lines pass through regions where it is known that the ground resistances are quite low. It appears probable, therefore, that the relatively greater severity of 60-kv. short circuits is in part due to the fault resistances being within the critical range. Consideration is now being given to the possibility of reducing the fault currents under phase-to-ground fault conditions by using transformers with delta connections on the 60-kv. side and possibly by removing the grounds from some of the transformer neutrals where more than one bank is located in a given station.

It was found by experience that very greatly improved operation of the 220-kv. system was obtained by reducing the time settings on the relays for the 60-kv. lines out of the Eagle Rock and Laguna Bell substations.

Governor Operation

In practically every case of a flashover to ground on the 220-kv. lines, the records obtained have shown that the governors on the Big Creek generators operate to increase the input to the machines. This effect, as shown by Fig. 10, is likely to produce instability. When a flashover occurs the capacity of the line for through power transmission is reduced, owing to the drop in voltage, and when the faulty section is finally cut out, the transmission capacity is reduced still further over that originally available. Also, the oscillations in phase position of the various synchronous machines require that a flow of power in excess of the average load on the machines be available to hold them in synchronism. Any increase in the average load will cause the peaks of the power oscillations to reach higher values, and if they then exceed the transmitting capacity of the system, the generators will pull out of step from the rest of the system. This point is illustrated by Fig. 22 showing how normal governor action may increase probability of pull-out, being the transient power limit of the system being represented by the line A. Curve B is a hypothetical curve showing the variation in power output of the sending

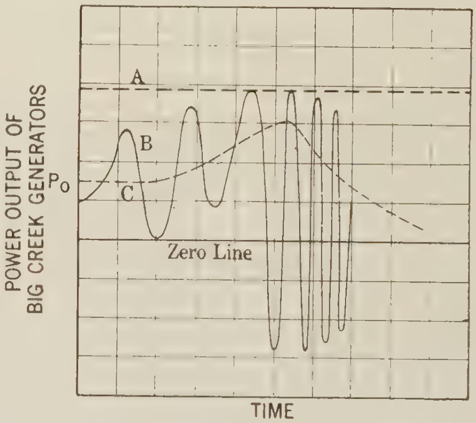

Fig. 22

generators, and Curve C is the prime mover input to them. It is assumed that the added power taken by the fault causes the system as a whole to slow down, thus making the governors of the waterwheels admit more water. The peaks of the power output oscillations increase until they reach the maximum capacity of the system at which point the momentum of the generators in their oscillation cannot be absorbed by the system and they pull out. When the machines overspeed, the governors finally operate to reduce the input as shown by the continuation of Curve C. The remedy for this condition is to have a system of control that will partially close the waterwheel gates upon the occurrence of a major disturbance, and later, after a proper interval of time, reopen them to their previous value.

The purpose of this arrangement would be to temporarily lower the input to the machines to conform to the temporarily reduced capacity of the transmission lines, and after the trouble is cleared, to gradually

resume the normal load. Since at light loads it is unnecessary to take any special precautions to obtain stable operation, the relay-selecting scheme would be arranged to prevent operation unless the transmitted load was in excess of a certain predetermined value. This scheme is now being given consideration for use on the Big Creek generators. Depending upon the rate at which the gates can be closed, the use of a device of this kind should materially reduce the number of disturbances causing interruption of service, and, in the case of those which do, should facilitate the restoration of service by permitting the system to pull together more rapidly.

Regulation

In every case observed with the exception of that illustrated by Fig. 15, loss of synchronism, if it took place, did not occur until one second or more after the beginning of the disturbance. This shows that an appreciable time is available in which the field excitation of the synchronous machines may be increased to conform to the additional requirements. This can be accomplished only if the voltage regulator is capable of responding quickly and accurately and the exciters are able to build up in voltage rapidly. The object of a quick-response excitation system is to rapidly build up a voltage across the field winding of a synchronous machine, to provide sufficient additional magnetomotive force to neutralize the demagnetising action of the short-circuit current flowing in the armature windings. Owing to the fact that with a high resistance fault the voltage on one of the good phases may actually rise, the ordinary voltage regulator, if connected to this phase, would tend to reduce the excitation. This possibility can be overcome by the use of a regulator operated by means of a positive sequence network, and the new generators for power house No. 2-A, in addition to having a quick response system of excitation, will also have this type of regulator.

Transmitted Load

Whether or not a given system is able to withstand a disturbance is determined by the particular combination in which the controlling factors occur, as discussed in previous paragraphs. It is therefore impossible to place a definite numerical value on the transmission capacity of the system. However, data are available on a sufficient number of cases of flashover to permit of curves being drawn, showing the percentage of flashovers which cause outages at different loads. The curves of Fig. 8 were drawn for troubles originating on the 220-kv. system only, for the over-all operation of the system and for those cases in which perfect relay operation was secured. These curves show that the probability of an outage increases with the load being carried. The permissible operating loads depend largely upon local factors, such as frequency and time of occurrence of disturbances and perhaps even more upon how far it is justifiable to increase the cost of power in order to achieve greater reliability of service, etc. On the Edison system most of the flashovers occur in the early morning hours, when the transmitted load is low, (as shown in Fig. 7), thus making operation at high loads feasible in the daytime. In regions where lightning is responsible for most of the flashovers and the plant has storage capacity, the load may be reduced upon the approach of a storm to minimize possibility of an outage.

Conclusions

1. There are various standards of service which may be considered. Perfect continuity is not economically feasible; the next best thing is to so reduce the effects of short circuits as to allow only momentary disturbances, thus causing but slight inconvenience to the consumer.

2. It has been brought out that one of the main factors in reducing disturbance and preventing loss of synchronism between the generating and receiving ends of a transmission system is the rapidity with which relays and switches can be made to isolate any trouble. It appears very probable that by a material reduction in the time now taken, troubles could be successfully cleared when transmitting much greater amounts of power than at present, and this same high standard of service could be maintained. Looking at this from another viewpoint, systems that might be furnishing but mediocre service would have that service vastly improved in quality by such change in switch operation, provided the transmitted load were not changed. On the other hand, unless it is possible to get extremely fast switch operation, less shock is produced when one end of a faulty section is cleared a short time after the other.

3. Quick response of generator field excitation to regulation aids in maintaining synchronism by preventing, so far as possible, a drop in generator field flux. The drop in generator terminal voltage will then be determined by the generator leakage reactance, being less with low values of reactance. Similarly, low transformer leakage reactance is beneficial.

4. It also appears that a device to decrease the output from the Big Creek generators immediately upon the occurrence of a short circuit will decrease the tendency to get out of step by reducing the transmitted load. Such a device might take the form of a relay operating upon the waterwheel governors. The greater part of the load so dropped would be picked up by generators at the receiving end, so that the net effect upon the system frequency would be inconsiderable.

5. One of the most important points brought out by the tests was the relation between the severity of the disturbance and the amount of ground current upon short circuit; this demonstrates the value of adopting means to limit short circuit currents. The higher the voltage of the system, the more pronounced is this effect.

6. The amount of power that can be transmitted

consistently over any given line depends upon several factors including the standard of service required, the exposure and susceptibility to outside disturbance, and the probability of these disturbances occurring at a time when maximum loads are being carried. This is well illustrated on the Southern California Edison Company's system where, due to the nature of the chief cause of short circuits, they have occurred at off-peak periods, resulting in a minimum of outages.

It may be suggested that under different conditions where causes of short circuits, such as lightning, might occur at any time, it would probably be advisable to take further precautions against outage unless conditions permit of a slightly lower standard of service.

7. All the records showed that synchronous condensers at the receiving end stayed in step with each other and their bus voltage; also all Big Creek generators would stay in step together so long as the generating and receiving ends of the line stayed in step.

8. Practically all short circuits have been single phase to ground and calculations for relay design and power limit should concentrate on this condition.

9. Short circuits on either 220-kv. or lower tension lines close to terminal substations will cause approximately equal disturbances to the 220-kv. system.

10. When a single-phase flashover occurs, there is an increase in total system load due to the power consumed in the fault. This additional load causes a transient redistribution of power between the different synchronous machines, which is largely determined by their kinetic energy and the electrical network, causing them to shift in phase position and thus set up power oscillations or surges. The magnitude of these surges depends upon a number of factors, such as the location and resistance of fault, transmitted load, etc. The ability of the system to absorb these oscillations without loss of synchronism depends upon the electrical rigidity with which the various machines are tied together, permitting a sufficiently high synchronizing power to be developed. The amplitude of these power surges will be reduced by anything that decreases the power consumed by the short circuit. Synchronizing power will be increased by decreasing the reactance of generators and transformers and by reducing the amount of line cut out to isolate the trouble.

Advance Planning of the Telephone Toll Plant

BY J. N. CHAMBERLIN[1]

Member, A. I. E. E.

THE advance planning activities of a large telephone company is a field of endeavor that perhaps is not very generally understood by those not intimately associated with the communication art. This may be due to many circumstances, the more probable of which is the fact that telephone service has grown to be one of the necessities of social and business life and, from casual observation, seems to differ but little in individual locations. In the small or large community, similar subscribers apparatus is in general use; wires and poles of like character are in evidence and service is apparently rendered in much the same manner. These observations are basically correct. In structural design and operating practises, however, widely different problems are encountered in the rendering of service in separate communities.

Satisfactory service to the customer and economic operation in all locations require continuous study of both the present and probable future service demands, operating practises and characteristics of the physical plants design. In the small communities or exchanges, as they are called, problems of less complexity are encountered than in the metropolitan areas. The solution of these, however, whether they be large or small, are important functions of successful operation. Small exchanges grow and change in character and the telephone company must so plan its activities as to meet satisfactorily the future conditions as they may present themselves and at the same time, provide a financially sound structure in the rendering of a universal service. As a community develops and more service is rendered, more than proportionate amounts of capital and labor are required in providing the service for each additional customer. Interconnecting devices or switchboards are limited to a definite number of subscribers lines. When the switchboards capacity is reached, new offices or replacing switchboards of larger size are required. The number of operators employed is dependent upon the amount of service rendered and as service demands increase, more operators are employed. Pole line, wire and cable are installed as needed to meet the expected future requirements of customers. The character and extent of this part of a telephone structure are governed by the size and density in population of the area served.

The average individual, not fully informed in the complexity of telephone equipment or the details of operation, is very apt, in his appraisal of the business, to use as a unit of measure, the telephone instrument. He fails to realize that, in a telephone system, separate and complicated pieces of equipment are

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permanently assigned on the switchboard to individual subscriber's lines and that large amounts of equipment and apparatus are required for the establishment of an independent channel of communication for each pair of talkers. The telephone instruments, channels of communication and switchboards are the mediums through which service is rendered. Therefore, the three components rather than any individual one should be used as a unit in a general analysis. Service, on the other hand, is what is being offered under the various tariffs and it, rather than any of the physical properties, is a more correct measure of value. If service is restricted as to hours, distances and types, the cost of rendering it lessens; likewise its value to the user.

The term "telephone plant" very aptly describes the structure by which communication service is rendered. It is ever varying in its charactristics and must grow in size and nature in a manner consistent with the demands resulting from the population within the area served. When people move into or within a community and want telephone service, the company must be prepared by the extension of its lines to give the service. As compared with other utility fields, the telephone business is somewhat unique in that applicants for service are not the only ones interested in obtaining it. The value of the service to those who already have it, is of course increased by the number connected with the system. Also the service rendered must always satisfy two individuals rather than one and must be available at such time of the day or night and for such duration as the customers, themselves, may elect.

During the pioneering days of the telephone business, little realization could be had of the development of the art to the state in which we find it today. To attempt, at the present, a detailed prediction of future attainments would result in but individual theory and is in no way herein attempted. Effort is to be made to simply set forth, in a very general manner, some of the fundamentals that are used today in advance planning, particularly as they concern long distance telephone service. In doing this, it will be necessary frequently to refer to some of the fundamentals underlying local or exchange plant planning, as such activities are intimately related to the planning of long distance service.

While similar to other structures in many ways, a long distance telephone plant is quite dissimilar, especially in regard to the ever present indeterminate demand that may, without any appreciable warning, be placed upon it. Local disasters and climatic disturbances repeatedly give rise to heavy service demands. These can, in no way, be anticipated as to time or importance. Their occurrence, however, must be expected and means provided in a general way for caring for these occasional surges in demands for service. Seasonal loads resulting from accelerated business activities occur at different times of the year in widely separated localities. The demand for service to and from recreation resorts during the summer months presents another rather indeterminate demand for service. These latter loads, as they are termed, can be better anticipated than the former as their annual recurrence can be made a matter of record and their characteristics closely studied.

The linking together of two separate communities of meager population, as was repeatedly done in the past, is incomparable with the demands for the network of circuits made upon the telephone company of today by the ever growing metropolitan and suburban areas. Closely allied to the demand resulting from increased population is the growing demand as a result of the increased use of the telephone in business and social activities.

Experience has indicated that the telephone service grows much more rapidly than the population because of the necessity of meeting the service demands of not only the new population but also the increasing demands of the existing population. The term population as herein used denotes families, rather than a per capita population, it being obvious that such a unit is more closely related to communication service requirements than would be a per capita unit.

It is, therefore, a function of good telephone management to estimate population increases as accurately as is possible in advance in order that facilities may be extended with confidence that the future service demands will be satisfactorily met and that they will be handled along basically sound lines and with maximum economy. This requires what are termed "commercial surveys" or "development surveys" which are detailed estimates of future expectancies. The compilation of these surveys demands a large amount of field work, the tabulation of existing statistics and forecasting of the probable changes in amounts and distribution of the future population. Analyses are made of the amount of the past growth and of the reasons for this growth. The factors affecting future growth are considered and evaluated, and estimates made of the most probable future population growth.

As any estimate of future population may be in error, due to occurrence of some unpredictable event, it is highly essential that the management be ever on the alert to observe the first indications and the importance of changing circumstances and conditions. Selected and highly trained personnel, therefore, are continually employed in analyzing the economic and business conditions of the community being served and are closely studying the details of the probable moves of population within and between both urban and suburban areas. Such prophecy as an estimate of the probable redistribution of the population as will result from better roads or improved transportation facilities between communities is a typical example of this development engineering. Another example and one which is highly important in local or exchange line development survey activities, is the forecasting of the effect that will result from the constant change of

individual properties from residence to apartment house and business purposes.

The estimates of future population are made of individual communities for a major portion of the area served and forecast the probable population for several periods into the future. These estimates picture the size, distribution and character of the future market for telephone service. Additional estimates of the service demands from this market must then be made so that the final estimates may indicate the probable number of telephones that will be required at different future periods. As both individual and party line service are usually offered in an exchange area and telephone plant investment and operating costs vary in the rendering of the several grades of service, it is necessary to proceed further with the prediction of the estimated "telephone development" by classifying it into the various types of service rendered. After this has been accomplished these data are transcribed in numerical form to large scale survey maps covering the area being studied. These maps are called "telephone line distribution maps," and serve to indicate the density and approximate location by small areas of the total number of anticipated subscribers lines.

When the features of the development survey, necessary to prepare the line distribution map have been concluded for individual communities, it is necessary to then make predictions as to the amount of service that will result from the estimated telephones. In telephone language this means the determination of the "calling rate" or average use of the service per customers station. In small communities this is not a feature of major concern. In the metropolitan areas, where several operating central offices are maintained it is a highly important function in developing the detail design of the future plant structure.

Interrelated and associated with the study of calling rates in a multi-office exchange area is a further activity which has to do with the forecasting of the direction of the flow of service between the several operating areas within the exchange. Between adjacent central office districts there usually exists a different community of interest among the customers than between non-adjacent offices or between residence and business areas.

The ratio of the present telephone development to the population, location, average number of daily calls per customers station, and the direction of flow of the past service is, of course, a matter of record. These statistics are extensively used in making predictions but in no way preclude the necessity for the exercise of sound judgment in forecasting the probable future trend of service demands and characteristics. Upon the results of these series of studies and forecasts, operating plans are adopted and construction details determined. It is therefore, apparent that this portion of advance planning work is a highly important part of telephone engineering.

In the exchange lines or local plant planning, these data are used to prepare basic plant layouts to be used as guides in construction and future extension work. These plant layouts, or "fundamental plans" as they are called, depict both present and anticipated future central operating centers, local service limitations, economic plant arrangements and such other pertinent data as may be reasonably forecast. Their preparation requires a large amount of time and study by a personnel that has a thorough knowledge of telephone fundamentals. Detailed consideration in these studies is given to the determination of the ultimate number, size and location of central offices. Comparisons are made of various types of equipment, operating methods and construction details. The wire mileage required in concentrating the subscribers lines as indicated on the previously mentioned line distribution map under different plans are determined, land values and costs of construction and maintenance estimated and studied before the selection of a plan is undertaken. In exchanges requiring but one central office, these tasks are comparatively simple. In the multi-office exchange, however, and those approximating such size, many additional factors, such as trunk and tie lines between central offices, present themselves as influencing factors in arriving at an ultimate decision. Many other features of importance are concerned in these fundamental plan studies but cannot be dealt with here in the time allowed for the subject in hand.

In long distance or toll line advance planning, these same data are used in the formulation of a long range basic toll line plant layout or toll fundamental plan. In these latter studies, however, it is necessary to analyze, among other things, the flow of calls between, rather than within, individual communities. How service between separate and distant areas is to be handled, where interconnection between circuits and recording is to be done, and how many circuits will be required to satisfactorily serve the long distance service demand over future periods of years, are the desired conclusions to be obtained from these studies.

The item of cost in relation to service finds its fullest application in these fundamental plan activities. Advancement in the art is to be anticipated and the cost of all progress must be judicially interpreted and forecast. Technical development is of necessity an all important factor in the giving and extension of communication service. Its mastery, however, in no way excludes the study of economies; on the contrary, it creates economic problems that require extensive study and ultimate solution before general application can be made of any individual improvement.

Many different general plans of varying details present themselves for solution during the activities concerned in these studies. These must be independently worked out and comparisons made, both from the service and cost viewpoint, before conclusions are formed. This is done through the medium of engineering cost comparison studies which usually express in

terms of equivalent present worths the total costs of the different plans over an extended cycle of years. Special problems concerned with detailed features of individual additions to the plant structure, quite naturally cannot be intimately dealt with and fully set forth in a general study of basic fundamentals. These must be studied as they arise during current activities dealing with changes and additions to the plant and their solutions obtained through individual study.

The engineering cost comparison study, in which the initial investment, deferred investments, annual charges and credits for future salvage returns of different plans of comparable design are analyzed, is a most important element in future planning. The initial and deferred costs of the different plans are usually very readily obtained. The annual costs and salvage credits to be anticipated at the termination of the service life of the plant structure are more difficult of correct interpretation. They are, nevertheless, of equal importance in the solution. Similar to all analyses of future cost factors, these engineering cost comparison studies involve the making of definite assumptions of future anticipation. Due to the climatic and human elements, that continually affect the service life and maintenance expense of a large part of a telephone company's investment, it is highly essential that the assumptions in these studies be based upon an intimate knowledge of present and anticipated factors, and that proper decisions be made in appraising the results that are indicated at the conclusion of the studies.

It is very necessary in their interpretation, therefore, to give thorough consideration to many intangible elements. A few of these may be cited as follows:

1. The practicability of the several plans under possible future changing conditions.

2. The adaptability of the separate plans to existing plant units and to future technical advancement.

3. The new money required to put the individual plans into effect.

4. The weighing of assured immediate economies of one plan with the estimated future economies of other plans.

There is no simple method for determining exactly how many toll calls will flow to or from individual communities. The experience of competent engineers and a thorough study of past and present statistics and related forecasts is the best available guide in planning for the expansion of the service. Extensive records are kept of the average number of long distance calls placed per customer's station; of how the originating traffic of individual communities is distributed over existing circuits; of the time consumed in making the desired connection or interconnection, and the average time the circuit is held for conversation.

For the purpose of planning, schedules of the call carrying capacity of the circuits under different operating methods and under different conditions as regards service delays have been formulated. Their application varies with the length of the circuit, number of circuits in a group, and the ratio of direct calls-to-calls requiring built up connections. In planning for the future, these theoretical circuit capacity schedules are set up on a premise of a different degree of freedom from service delays, on account of no circuit conditions, occurring on a given number of calls. By a no circuit condition is meant that all circuits in a particular circuit group are in use at the time a connection is desired.

The determination of future circuit requirements over long term periods is carried on by the use of these schedules and the estimates of future traffic. In predicting the immediate necessity for circuit rearrangements and additions they are, however, modified to meet the circumstances under individual review. As operating conditions and local service demands result, a considerable varying of speed of service and circuit capacity between individual communities, it is necessary that intensive study be given to individual groups. Such matters as the size of the circuit group, the type of service to be rendered, the average length of conversation, and the distribution of the traffic through the hours of the day, must receive careful consideration.

A record is usually taken over a period of 20 business days during the month, in which the distribution of the traffic is representative of the conditions for which the plant is to be engineered. When encountering conditions that are not similar throughout the territory, this record is adjusted for the different seasonal conditions. As circuit groups do not experience their greatest traffic in the same month or maintain the same trend throughout the year, supplemental checks of the traffic volumes are made. Ordinarily additional circuits are provided less liberally for groups showing a traffic peak of relatively short duration than for groups carrying heavy traffic over periods of two or three months. These checks are also studied for the purpose of determining the possibility of overflowing traffic to groups having margins and of rearranging the circuit layout either temporarily or permanently to meet fluctuations.

These detailed studies of circuits and load characteristics have been used extensively in the past in determining the immediate and early necessity for circuit rearrangements and additions to individual groups. Today it is necessary to use them as a guide in the projection of future requirements over long periods of years. This is due to the changing design of long distance telephone plant and is made necessary by the installation of a large portion of the circuit facilities on a somewhat different basis than in former years.

Until a comparatively few years ago, practically all long toll circuits were of open wire construction; that is, individual wires separately attached to crossarms on the poles. These have been installed as required and were a natural development due to the small number of circuits required to handle early day long distance

demands. The wires have very generally comprised two sizes, namely, No. 8 Birmingham wire gage, (165 mil.), weighing 435 lb. per mi., and No. 12 New British standard gage, (104 mil.), weighing 173 lb. per mi. These two types of uninsulated wire have admirably lent themselves to the many changes and improvements in the communication art. For many years the limits for the highest grade service with these conductors were approximately 400 and 200 mi., respectively. The development of associated equipment, however, has so increased the distance over which service may be rendered with these sizes of wire, that today finds them in general use over distances of thousands of miles.

The introduction of the inductance or loading coil on open wire circuits, many years ago, so reduced the attenuation loss of open wire circuits that satisfactory voice communication was greatly extended in range. Distance of transmission on open wire circuits was later further increased by the installation of the mechanical repeater into the circuit to be used in conjunction with the loading coil. Experience, however, soon indicated that improvement must be made in the uniformity of the amplification given by the repeaters in order to raise the intelligibility of the voice transmission to a higher standard. This led to the use of the vacuum tube repeater which economically and satisfactorily eliminated the limitations of the mechanical type repeater. As a result, the vacuum tube repeater soon replaced the mechanical type and is today exclusively used in voice amplification.

Improvements and modifications in the design of the repeater and reduction in its cost of manufacture have made it desirable and economical to use it more frequently on long-distance lines in lieu of the loading coil. At present, therefore, we find the use of the loading coil on open wire lines very generally restricted. In its place is found the vacuum tube repeater, with service range increased and quality of transmission improved.

The non-loaded No. 165 and 104-mil open wire circuit have also permitted the development and use of the higher frequency ranges in voice communication. Without distortion or sacrifice to the quality of the service, frequencies ranging up to 30,000 can be used on non-loaded repeatered open wire lines. The application of these higher frequency ranges to what are termed "carrier current systems," in voice communication, has extended the field of use of the open wire circuit many fold. In brief explanation of this statement, a typical open wire line, carrying four fully equipped ten pin crossarms, is capable of providing the following voice channels. Four crossarms supporting 40 wires of the standard configuration of 12-in. horizontal and 24-in. vertical separation, when properly transposed, produce 20 physical and 10 phantom circuits or a total of 30 voice-frequency talking circuits. By the proper coordinating or additional transposing of 8 of the wires on the top crossarm four carrier current systems can be superposed on the 8 wires. As each system is capable of producing 3 speech channels a total of 12 additional circuits is thus provided. Without any loss in the number of voice frequency circuits on the lead four similar carrier systems with like circuit possibilities can be superposed on eight wires of the third crossarm. This complete arrangement therefore increases the speech channels on a 40-wire line from 30 to 54 circuits or nearly one hundred per cent.

Carrier current telegraph systems of ten channels each can also be similarly superposed on the open wire circuits, thus in another manner, greatly extending the use of open wire for communication service. At the present time it does not appear economical, due to the excessive expense of balancing the open wire for purpose of eliminating interference or "cross-talk" to superpose telephone carrier current systems of the three channel type on adjacent crossarms.

These three-channel carrier systems require highly expensive terminal equipment and well insulated and evenly balanced open wire lines. The economy of their installation generally speaking is confined to lines of 150 mi. and over in length. Often times, however, major reconstruction work on a pole line that would be required by additional open wire placements can be advantageously deferred by the judicious use of the carrier systems. Recent developments in high-frequency systems have resulted in a new system of one channel. This type is proving economical for superposing on open wire lines of approximately 50 mi. in length.

The rapidly increasing demands for toll service several years ago indicated many difficulties in providing for future long distance communication service on a wholly open wire basis. The number of open wires that can be placed upon a pole line is limited. The number of pole lines that can be constructed along highway routes is restricted and the costs of purchasing private rights-of-way for open wire lines is becoming excessive. These conditions prompted the development of some other practicable method of providing for the increasing number of toll circuits.

To meet this situation, effort was made to provide means which would permit of satisfactory conversation over long lengths of cable. In other words it appeared desirable to provide along one path a greater number of circuits of a type that require less space and structural support. In this endeavor highly successful results have been attained. Satisfactory conversation can now be given over an extended network of cable plant. Repeater operation appears to have solved the problem of distance and in so doing has made possible reductions in the use of copper to approximately 10 per cent of the amount used in open wire circuits of equal length. For example instead of the No. 8-gage open wire weighing 870 lb. per circuit mi. and the No. 12-gage weighing 344 lb. per circuit mi., the conductors, which are extensively used today in cable design weigh but 80

and 40 lb. per circuit mi. In the cable type of construction from 100 to 300 voice frequency circuits are provided in a cross sectional area of less than 6 sq. in. To accomplish this, relatively small gage wire must be used and some dielectric other than air must be provided for maintaining separation of the wires.

Two types of cable conductors present an economic balance at this time for general use. These comprise 16-gage wire, weighing about 40 lb. per mi. and 19-gage wire, weighing about 20 lb. per mi. These wires are each individually insulated by means of a spiral wrapping of paper ribbon of approximately 0.004 in. thickness and 0.625 in. in width. The wires are twisted into pairs, the pairs laid up into groups of 4 wires, termed "quads" and the "quads" stranded together and enclosed in a lead-antimony sheath of approximately ⅛ in. in thickness. In a large portion of toll cable installations it is found economical to provide a complement of both sizes of conductors in an individual cable sheath. This feature can be determined only after an extensive and detailed study of the use to which the individual circuits are to be placed. In a majority of instances comparisons must be made as to the economies of a larger gage with those of a smaller gage provided with a greater number of telephone repeaters, it being possible to obtain the same grade of circuits having given characteristics, by either size of conductor equipped with a different number of repeaters.

It is conceivable, although obviously impracticable, to design all circuit groups on a toll lead as individual units. Practical operation requires the centralizing of loading coils and repeaters at a minimum of locations. In the average cable installation loading coils are placed at regular intervals of approximately 6000 ft. and repeaters at approximately 50 mi. intervals. In locating these latter, consideration must be given to housing facilities as from one hundred to several hundred repeaters are usually installed at a given location. They must also be located in close proximity to the location dictated by electrical requirements.

Toll cable construction presents many advantages over open wire plant. It provides at one time an equivalent number of circuits that are offered by seven or eight open wire lines. The ever annoying foliage interference occasioned on open wire circuits passing through wooded sections is largely eliminated by cable construction. Of major importance also is the relief afforded from service interruption occasioned by sleet and wind storms and the resultant costs of the restoration of service.

Thorough studies of the economic design of toll cables are important before proceeding with an installation. Due to the many circuits provided at one time and the relative high cost of cable construction it is necessary in economic planning to design a cable to serve for an extended period of years into the future. This requires not only an intimate knowledge of the present use to which an individual cable is to be placed but also a well coordinated plan of its fitness to form an important unit in an ultimate cable network.

In long-distance wire communication, therefore, consideration is given in advance planning to the provision of three types of service facilities. Between the scattered and sparsely settled areas, the open wire circuit is at first provided. As demands for more service are encountered additional facilities are provided by means of more open wire or the superposing on existing wire of carrier current systems. Between the well developed and fast growing areas, however, where an extensive network of circuits is already in service the matter of planning for future additions is a decidedly different problem. Here is encountered the solving of many problems relative to the continuance of open wire construction versus toll cable installation.

Questions of route, both as to desirability and permanency of location are of major importance in designing additions and changes in the character of construction. In the early days of the telephone business this was not a matter of great concern. With electrical development in the power and communication fields and the gradual extension of both services, the problem of the coordination of the network of wires makes necessary an intimate study of the induced disturbances that may result when wires of either service are located in close proximity to wires rendering another type of service.

Many fundamental differences exist between power and telephone transmission systems. The former transmits large amounts of power usually at relatively low frequencies while the latter transmits speech waves through the use of a very small amount of electrical energy at a comparatively high frequency. Even with the use of relatively small amounts of electrical energy in wire communication, the economy of placing circuits close together and of superposing several channels of communication on each pair of wires, justifies and requires an elaborate scheme of coordination between the telephone wires themselves to eliminate mutual interference between channels. These requirements are closely related to those for prevention of interference from external sources. Induced disturbances from electrical circuits rendering other services, when in close proximity to communication channels, may seriously interfere with satisfactory voice transmission and cause interruptions to service, damage to plant and hazard to personnel.

This subject of interference from other sources has been extensively discussed on previous occasions. Reference is made to it in passing for the purpose of indicating the continued importance of coordination work by those concerned in the advance planning of telephone and power long distance service. If the more general use of toll cable construction should eliminate the inductive coordination problem of today it would indeed be fortunate. Such attainment however,

cannot be anticipated. Freedom through separation from other electrical circuits and the cooperation in the application of remedial measures by all wire using companies must continue to be effected in the planning, maintenance and operating practises of the different electrical systems. In the advancement of such co-operative effort notable contributions have been made by the inter utility joint committees, such as the General Joint Committee of the National Electric Light Association and the Bell Telephone System.

Other problems, not of an electrical nature, are concerned with the construction details of both open wire and toll cable installations. Pole structures must be designed to withstand not only the dead weight of the anticipated attachments but the storm stresses that may occasionally be experienced. These of course vary in different locations and are an individual field of study and research. Studies of this nature are not confined in particular to the telephone business but they are an important element in the work of rendering proper service. Sub-surface structures, such as conduits and splicing vaults form a large item of investment in all telephone companies plant. This type of construction is rapidly being extended, particularly in connection with extensive toll cable conditions. Underground conduits, into which cables may be drawn, offer reasonable permanency of location, freedom from fire destruction and the devastating effects of climatic disturbances. In order to obtain economies in underground construction however, it is necessary to provide for many years into the future, therefore well established fundamentals must underlie any major conduit installation. In this connection it differs from the other branches of advance planning work only in that it usually concerns the provision of a type of plant for greater periods into the future.

The results obtained by making the studies which have been very briefly discussed indicate the anticipated relative economies of the future plant structure under assumed conditions. It is necessary however, before undertaking any major plant work, particularly if large expenditures are involved, to formulate a well balanced and orderly construction program. This is a very essential part of advance planning. Materials and labor must be available at widely separate locations and at prearranged periods and all unfavorable reactions to the service while carrying on the construction program must be avoided. For purpose of indicating the scope of these planning activities and their results the following brief review is given of a portion of the Pacific Telephone and Telegraph Company's present toll plant structure and current extension program.

In the Northern California area of the Pacific Company's territory, comprising a majority of the communities in the State of California situated north of the Tehachapi Mountains, there are some 380 separate company operated exchanges. These vary in size from the small hamlet of a few inhabitants to the large cities of several hundred thousand population. Interconnecting and serving these localities with long distance telephone service are 178 main or toll center groups of circuits and 424 so called tributary circuit groups. At the present time most of these are in open wire construction. In planning for the future, quite naturally the major problems center around the larger and more rapidly growing groups. Correct solution of the future service on these groups however, cannot be obtained without thorough consideration being given to the tributary groups. This is being carried on by members of the Pacific Company's staff. Many circuit miles of open wire construction is included in the future program. Extensive carrier current systems are contemplated and approximately 1000 mi. of toll cable installation is being designed for the provision of service over the next 10 year period.

Within the past 12 months a 90-mi. section of this cable network has been completed between the San Francisco Bay area and Sacramento, California. The cable was designed to provide 295 voice communication channels for rendering service to Sacramento and points north and east. Liberal provision was also made for service to intermediate points. The cable is of 19 and 16 gage design, is equipped with loading coils at intervals of 6000 ft. and is provided with repeater service at the town of Crockett, located 30 mi. northeast of San Francisco. The repeater station is equipped at the present time with 100 repeaters and is designed to house approximately 200 additional repeaters over the next few years. This toll cable has been designed for extension northward and eastward at a future date, at which time it will form an intimate unit of a cable network extending very generally throughout the State of California.

In the 1000 mi. of toll cable network included in the present program, studies indicate the desirability of proceeding with the installation of approximately 100-mi. of cable per annum. A large part of this will be along existing open wire routes, although considerable relocating will be required and many underground sections will be constructed.

In the San Francisco Bay area there exists today an extensive toll cable network. This provides cable circuits to and between surrounding communities and toll entering facilities for the long distance open wire circuits radiating from the San Francisco Exchange. The continued maintenance and future planning of a large portion of this network presents an additional and independent problem, not previously referred to and not very extensively encountered in other localities. This has to do with the planning of a large amount of submarine cable plant.

San Francisco Bay is an extensive body of water, both in area and depth. To cross it at strategic points with communication service and place the necessary plant structures in reasonable permanent locations, requires the use of submarine cables of closed sheath lengths of

from 10,000 to 13,000 ft. These cables must be maintained at depths ranging to 200 ft. In the crossing of the Bay from San Francisco to the East Bay communities, a water distance of approximately 4 mi., two 10,000 ft. sections are required to form an individual cable. The presence of Yerba Buena Island about mid-distant makes it possible to so sectionalize the cables into two units. This is a fortunate circumstance as advantage can be taken at the shore of the island to install cable loading coils.

In the short haul circuit groups rendering transbay service between the Bay area communities there is in use at the present time approximately 1400 circuits. Some conception of the magnitude of this number of voice frequency circuits may be obtained by realizing their equivalent number expressed in open wire. Were it possible to render this transbay service with standard open wire construction there would be required 24 individual pole lines each supporting 8 crossarms of 10 wires each.

Until a comparatively short time ago all circuits entering and leaving San Francisco, with the exception of one very short circuit required in their path the use of submarine cable. This was a very undesirable situation due to the ever present hazards to that type of plant and the serious service interruptions that usually accompany a submarine cable failure. Recent local developments and major toll underground cable extensions, have made possible a partial change in this regard, although it will continue to be necessary in providing future additional service to install and maintain a large amount of submarine plant and equipment.

In the advance planning of these submarine facilities attention is given to the judicious safeguarding of the plant and to the adoption of such operating methods and arrangement of circuits that will require a minimum number of submarine cables. As the volume of service over individual circuit groups and plant conditions permit, circuits previously interconnected at or switched through San Francisco, are otherwise routed. While the development of economies that may be anticipated from a change in circuit routings is an important part in the advance planning of other parts of a telephone plant as previously referred to in the fundamental plan activities it is of major importance in the planning of toll circuits across San Francisco Bay.

Many other and equally important features of telephone long distance advance planning could be set forth in this discussion. Those of an electrical and mechanical character have been often presented in various forms and therefore have been omitted. This has been done with no intent to stress the importance of any part of the activities concerned with the advance planning of long distance service but more in an endeavor to briefly set forth certain fundamentals of the work that are not generally realized by those not connected with telephone work. While classed a branch of the electrical profession, telephone planning and operation comprehends important elements not at all electrical in their character. Electrical phenomena and their adaptation to the art of communication are essential features, but of equal importance is the solution of problems unrelated to the electrical science. Successful management of a telephone company as a result of these circumstances, depends in part upon the study and application of electrical accomplishment, in part upon the analysis and forecast of economic conditions prevailing and anticipated in the area being served with communication service and in part upon the solution of mechanical problems relating to the construction and maintenance of a plant structure, the whole combined to render an economic service and produce a fair return on the investment.

ELECTRIC HEATING FOR AVIATORS

Mountain climbers who attain freezing heights suffer from cold in spite of their physical exertions but aviators who soar to even bitterer temperatures can keep warm in spite of the fact that they must sit motionless as their planes climb to "the roof of the sky." They keep warm electrically. The latest development in flying equipment is a set of clothing warmed by wire, even to the glass of a flier's goggles.

Projecting from the bottom of the fuselage of the airplane is a tiny, cigar-shaped instrument carrying a propellor at its front end. The wind current created by the motion of the 'plane drives this midget propeller. It turns a small electric generator manufacturing current for use on board. A wire from this generator, running through a control switch, connects with the clothing the aviator in the cockpit wears. His inner jacket is heated on exactly the same principle as the electric hot pad familiar in most homes. A cord runs down each sleeve to warm the backs of the flier's gloves and cords running through each trouser leg carry electric heat to the soles of inner shoes.

Since the aviator who climbs to great heights must wear heavy furs and breathing apparatus, thus closing off his face from contact with the air, his goggles would, of course, frost over and become opaque were it not for a system of hair-like wires threading back and forth between layers of glass in the lenses. These heat the glass sufficiently to keep the lenses clear. Thus electricity serves the aviator in many ways other than to spark his engine, to furnish light on the instrument board, to operate his radio equipment and to perform the other routine functions aboard ship.

Abridgment of

Electric Strength of Solid and Liquid Dielectrics*

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Synopsis.—*This paper was prepared by a subcommittee of the Committee on Electrical Insulation of the Division of Engineering and Industrial Research of the National Research Council. The general purpose of the committee is to foster research on dielectrics and its initial activities have been confined to the preparation of a series of summaries of the published literature on this subject.*

The subcommittee which presents this paper is the second one to report, it having been preceded by a paper on dielectric absorption and theories of dielectric behavior, by Chairman J. B. Whitehead, which was published by the A. I. E. E. in 1926.

The second paper under the auspices of the committee was inspired by the first one, and was an original exposition of Clerk Maxwell's theory of the double layer dielectric, by Professor Murnaghan, published by the A. I. E. E. in 1927.

The present paper, like the first, is a summary of existing literature which, it is hoped, will afford a starting point for original research in many directions. It is hoped that the discussion by the Institute will bring out obscure phenomena and new interpretations of the data reviewed. The report starts with a consideration of the general subject of instability in electrical circuits, and an explanation of instability in the case of dielectrics, in terms of a stress and strain characteristic. This is followed by a discussion of distribution of stress and strain in non-uniform fields, and their relation to breakdown. The reversible and non-reversible phenomena of dielectric failure are considered, the former in relation to the electron theory and the latter in relation to the pyroelectric theory, and the bearing of both upon the time—voltage relation is indicated.

The latter part of the full report is devoted to the relation of breakdown voltage to various factors, such as insulation thickness, insulation area, the electrode form, heterogeneity, temperature, rate of voltage, variation, pressure, etc. Final conclusions are given in the full report which summarize in a few words the present state of the art, as it may be judged from published data.

* * * * *

Instability

It is helpful to consider dielectric failure as the phenomenon of instability which exists when the voltage across the dielectric has been increased to a certain critical value beyond which the current increases more or less in unpredictable ways while the voltage tends to fall. Perhaps the first clear statement connecting the failure of dielectrics with the general phenomenon of instability is that of Steinmetz[1] in 1923 when he said that "the view is gaining ground that the mechanism of dielectric failure is a phenomenon of the instability of the so called constants of the material."

Stress-Strain Characteristics

It was, however, a research by K. W. Wagner[2], initiated in 1914, which gave the first quantitative data on which to base a satisfactory theory. This physicist was the first to ascertain the volt—ampere characteristic of a solid dielectric, and he showed that the characteristic curve consists of a straight line corresponding to Ohm's Law, a curve which becomes vertical, *i. e.*, parallel to the current axis, and finally slopes backward, corresponding to a rising current with falling voltage, as shown in Fig. 1.

It is not difficult to obtain the first two parts experimentally, but the third part corresponds with a condition of unstable equilibrium and is normally passed at such an immense speed that it cannot be observed unless special precautions are taken.

Wagner succeeded in plotting the entire curve by using an electrode of such high resistance that the circuit, as a whole, had stable characteristics, *i. e.*, current rising with voltage, and thus stabilized the dielectric in the same way that a ballast resistance is used to stabilize an arc. Current and voltage readings were first taken with the electrodes in contact with one another, and then with the dielectric between. The difference in voltage for the same current, in the two

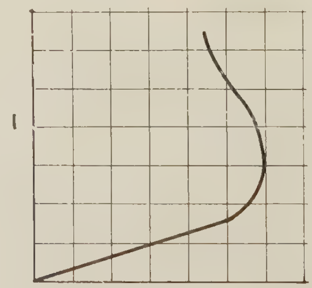

Fig. 1

cases, was the voltage across the dielectric corresponding to this current. The general form of these characteristics has been verified by others[3,4,5] who used hot cathode rectifiers in series with the dielectric, to restrain the current.

In all these tests, direct current was used. Corresponding data for alternating current have not yet been obtained, indicating a fruitful field for research.

No work appears to have been done on liquids in an effort to determine the volt—ampere characteristic although Gunther-Schulze[6] made determinations of dielectric conductivity over a considerable range of

*Abstract of a report to the Division of Electrical Engineering of the National Research Council.

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1. For all references see bibliography.

stresses and found a tendency for the current to decrease with increase of voltage. This may be explained by consideration of the fact that the voltage was gradually increased and this gave additional time for impurities, which apparently constitute a considerable number of carriers, to be swept out of the field.

The shape of the curve for solids has been explained by Wagner on the basis of the negative temperature coefficient of resistivity characteristic of all dielectrics and by Peaslee[7] as due to ionic migration.

Dielectric Overstressed Without Injury

That part of the dielectric which has $\frac{dI}{dE}$ negative is overstressed; that is, it would fail but for the stabilizing action of the remainder of the insulation, which acts as a ballast resistor.

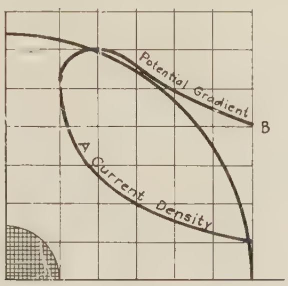

Fig. 2

Wagner, working simultaneously along similar lines, described an experiment on a dielectric which had been unequally stressed for a short time so that one part was stressed above the point where $\frac{dI}{dE} = \infty$, and he showed that this over-stressed part, when subsequently tested alone, had lost none of its dielectric strength.

Stresses in a Dielectric with Non-Uniform Field

The next step toward putting the behavior of dielectrics upon a quantitative basis was taken by P. L. Hoover[8] who showed that the characteristic curve could be expressed in terms of potential gradient and current density and that therefore if the current density be plotted for the various parts of an unequally stressed dielectric, the corresponding potential gradients and values of $\frac{dI}{dE}$ can be plotted from the characteristic curve and the behavior of the dielectric deduced therefrom. In other words, if the current densities at various points be computed from the resistivity and geometrical configuration, the corresponding stresses may be derived from the characteristic curve.

Thus, in a dielectric between co-axial cylinders, *i. e.*, a single-conductor cable, if the same current be assumed to flow in all parts of the circuit, the current density must decrease radially, and may therefore be represented by an hyperbola, such as A in Fig. 2. Referring now to the volt—ampere characteristic, Fig. 1, as each value of current density corresponds with a definite potential gradient, a curve representing the potential gradient at all radii may be plotted, as shown by the curve B in Fig. 2

If the current density is increased, the maximum of curve B moves outward. In doing so, the area to the left of the maximum increases, while that to the right decreases. The curve is not symmetrical; hence there is a certain current at which the area enclosed by the curve is a maximum. But this area is the total voltage between cylinders. Hence there is a value of the total voltage E such that $\frac{dI}{dE} = \infty$. This will be the breakdown voltage.

Hendricks[15] mentions the results of tests on transformer oil using concentric cylindrical electrodes of different sizes, and finds that the breakdown strength as calculated by the ordinary logarithmic formula for the maximum stress is not constant. On the other hand, Peek[16], as a result of similar tests, comes to the conclusion that there is a definite maximum stress, (36 kv. per cm.), which is the value at which an increase in conductivity results from ionization by collision.

Another factor which may be of considerable importance in some cases and which seems to have been generally overlooked in the computation of stresses although it is made the basis for many explanations of the phenomenon of absorption, is the combined influence of resistivity and specific inductive capacity on distribution of stress.

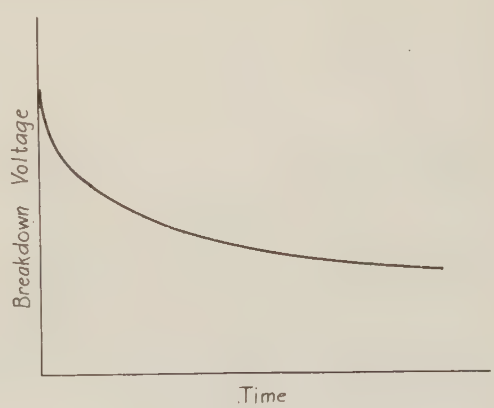

Fig. 3

Irreversible Deterioration

Thus far we have dealt exclusively with so called momentary stresses, *i. e.*, those which are not maintained sufficiently long to produce chemical deterioration of the insulation.

All solid dielectrics on which published data are available show some kind of permanent deterioration when exposed to stresses over a certain critical value. Thus it was found by F. M. Clark[31] in 1925 that pro-

longed stresses permanently injure oil-impregnated paper insulation and that the injury is cumulative, even if the stresses be applied intermittently. Other experimenters have verified this conclusion and extended the rule to a wide range of materials. Clark also verified Wagner's observation that *momentary* overstressing produces no appreciable permanent injury.

The nature of the injury depends upon the material, and may be any of the following:

A. Direct effect of stresses,
   a. Polymerization and condensation,
   b. Redistribution of component materials according to specific capacity,
   c. Change in surface tensions between component parts,

B. Indirect effect of stresses,
   a. Thermal effects such as carbonization,
   b. Chemical combinations such as oxidation,
   c. Electrolytic effects.

An example of polymerization is the formation of the solid material provisionally known as "X," in mineral oils.

Change in surface tensions is one of the important factors in the failure of oil impregnated cables. In such composite insulations composed partly of solid and partly of liquid materials, an air or vacuous pocket may serve as a center of disturbance, and the liquid material will be driven away from the pocket, thereby enlarging the latter[32]. Such oil free spots would ultimately link together, and ionization would be established, leading to charring in dendritic or tree-like patterns[35]. The projection of oil from places of high stress to those of low stress, in this case, is apparently due to an increase of surface tension between air and oil as compared to that between paper and oil.

Little is known about electrolytic effects but they are under investigation in the case of glass.

The redistribution of moisture by endosmose may be a factor of some importance, as indicated by the work of S. Evershed[34] in 1914. Endosmose is a motion of films of water along the walls of an insulator, due to the water being electropositive to practically all solid insulating materials, and being, therefore, drawn through the pores of the solid toward their electronegative ends. The alinement of threads of moisture has the effect of partially short-circuiting the dielectric.

Time–Voltage Relation

The relation between the breakdown voltage of a dielectric and the time of application of the voltage is of the character shown in Fig. 3, *i. e.*, the breakdown voltage for short periods is high and falls off rapidly with increasing time, whereas that for long periods is comparatively low and changes little with the time.

The general form of the curve suggests two influences at work, one corresponding to an action which is reversible up to the point of breakdown and the other, to a cumulative and irreversible action. Both of these actions have been observed and explained. It is therefore clear that for any finite period of application of voltage, these cumulative effects will cause progressive deterioration until the bulk of the dielectric has become worthless as a ballast resistor, and the remainder of the insulation is carrying such a current that the critical point, where $\frac{dI}{dE} = \infty$, is reached therein, and failure occurs practically instantaneously. Thus each point on the time–voltage curve represents two actions varying in degree with the time. This conclusion is verified by the work of Mündel as analyzed by Bush and Moon.[79]

True liquids do not seem to be influenced by the time of application of the voltage although there is a time-lag for rapidly applied voltages and Peek[21] has found this lag to obey almost the same laws as he established for gases. Dieterle[22], in a series of tests with semi-fluid materials intended to determine the relations between the magnitude of continuously applied stress and the time to produce failure, obtained results similar to those already noted for solids although they are too few to permit establishing a mathematical expression.

Pyroelectric Theory

Miles Walker[23], in 1912, was probably the first to call serious attention to the dielectric loss—temperature relation as a factor in dielectric failure. He was followed in 1917 by A. F. Bangs and H. C. Louis, and W. S. Clark and G. B. Shanklin[24] and in 1922 by D. W. Roper[25], all of whom dealt with average losses in relation to mass heating of cable dielectrics. At about this time C. P. Steinmetz and J. R. Hayden contributed ideas as to the general application of this theory and coined the name "pyroelectric theory."

K. W. Wagner[2] in 1922 went a step farther by taking into account the well-known unevenness of dielectrics and considering the effects of a filament of higher dielectric loss, or, as he expressed it, lower resistivity than the surrounding mass. He laid particular stress on the well-known fact that dielectrics, unlike metallic conductors, possess a negative temperature coefficient of resistivity; *i. e.*, their resistivity decreases with rising temperature. Hence, if a spot or filament of comparatively low resistivity exists in a dielectric, the extra $I^2 R$ loss which occurs in it will tend to raise its temperature, which in turn by decreasing the resistivity will increase the current and temperature, and so on accumulatively until failure occurs due to burning.

This theory was ingeniously developed by Wagner as a general theory of dielectric failure by assigning an empirical equation to the temperature—resistivity relation, and assuming arbitrarily a certain diameter for the hot filament. The quantitative results obtained were later found to depend very largely upon the value assumed for this diameter. Moreover, work by L. Dreyfus[26], H. Rochow[27], W. Rogowski[28], Von Karman[29],

H. Gabler[5], and others, has shown that the theory, as developed by Wagner, is untenable, both from a theoretical standpoint and because it yields numerical data which are widely at variance with facts.

The failure of Wagner's theory in a quantitative sense should not be interpreted as discrediting the general pyroelectric theory, as cumulative heating is undoubtedly a factor in many cases of dielectric failure. It is not that the theory must be discarded but that it must be amplified and made part of a more general and complete theory.

There seems to have been no attempt to apply the pyroelectric theory to liquids and indeed it is hard to see how this could be done since the existence of convection currents would tend to mask any of the detail phenomena assumed for solids.

Electron Theory

Thus far, our studies of dielectric behavior have led us to explain failures in terms of volt—ampere characteristic and chemical deterioration under stress. To be consistent with the spirit of the times, explanations of these actions must be sought in the electron theory.

Considerable half-hearted groping in this direction might be recorded, involving ideas of ionization by collision or indefinite displacement or mobilization of electrons, but no really definite results have been obtained. Indeed, it is hardly reasonable to expect any more until physicists have agreed upon an atomic structure which explains the simpler phenomena of chemistry and physics.

Since the preparation of this report, however, an important contribution on this subject has been published by Joffé, Kurchatoff and Sinelnikoff[80].

Gunther-Schulze[6] discards the theory of ionization by collision as presented by Peek[21] on the ground that the high viscosity and low mean free path require extremely high potential gradients to produce ionizing velocities and these in turn mean localized field distortions far beyond values that are reasonable to expect. Starting from the data of Freise[36] and Koch[37] on the relation between pressure and dielectric strength, he notes the rather surprising qualitative agreement between the behavior of liquids and gases under pressure, and then suggests that slow moving ions of considerable mass leave vapor tracks in the liquid and that in these spaces, as well as in the spaces formed by occluded gases, ionization is produced by collision. He also suggests that there may be originally small vapor spaces, which serve equally well to permit higher localized velocities of sufficient value to produce ionization. In these spaces the mean free path and viscosity would be those corresponding to a vapor and not to a liquid, so that the required field strength would not be excessively large. Schumann[38] presents a somewhat similar theory but calls attention to the need for obtaining further and more accurate information as to the mechanics of moving ions and other charged particles within liquids.

Research to be Undertaken

It might seem to a superficial observer that the theory of dielectric failure is fairly well mapped out and that only a little remains to be done to round it to completion. Such, however, is far from being the case, and the full report is largely devoted to consideration of some of the great mass of inconsistent experimental data which need elucidation and present a fertile field for the laboratory worker.

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CORRESPONDENCE

MAXWELL'S THEORY OF LAYER DIELECTRIC

To the Editor:

Referring to the discussion of Dr. Murnaghan's paper on Maxwell's theory of the layer dielectric, published in the July issue of the Journal of the A. I. E. E., p. 727, I am sending you a few comments on the same subject, with which we have been concerned for sometime.

Dr. Murnaghan's expression for the charging current in the most usual case of a layer dielectric is certainly an important contribution to the mathematical analysis of dielectric phenomena. We understand that it is hoped that this expression will be a convenient basis for the experimental check of Maxwell's theory being attempted to Dr. Kouwenhoven at Johns Hopkins University. With a view to checking Maxwell's theory, it is stated that an endeavor is being made to obtain several perfect dielectrics having no absorption and different conductivities and dielectric constants, and to then measure the absorption presented by the mixture of these perfect dielectrics. Even if perfect dielectrics can be found for the experiment, which we doubt, our experience with dielectrics containing several kinds of imperfect materials has shown us the influence on the resultant absorption of the association of these materials. We believe, therefore, that there can be no doubt that a mixture of several perfect dielectrics having no absorption but different conductivities, and dielectric constants, will show absorption. On the other hand, we do not believe that that absorption will follow exactly the mathematical laws established by introducing into the equations of Maxwell's theory the values of the conductivities and dielectric constants of the perfect dielectrics composing the mixture. And this is not because Maxwell's theory is erroneous, but because equations established for the case of layers cannot apply in the case of a mixture, for the reason that a lot of conditions, such as the breaking of the lines of force at the surface of separation of two particles of different kinds of dielectric and the influence of voltage across a particle on the conductivity in such a particle, will cause the absorption to differ in its behavior from the laws established in the case of a body composed of layers of perfect dielectrics having certain definite conductivities. We think therefore that one would not be justified in condemning Maxwell's theory in case the absorption measured on mixtures of dielectrics, such as are being prepared by Dr. Kouwenhoven, should not follow predetermined equations.

E. R. Leghait.

Abridgment of

A Precision Measurement of Puncture Voltage

BY V. BUSH* and P. H. MOON*

Fellow, A. I. E. E. Associate, A. I. E. E.

***Synopsis.**—A description is given of an apparatus for the automatic determination of the dielectric strength of thin sheet insulation. The machine makes about 1000 breakdown tests in a day. Almost no attention is required, thus reducing the human element to a minimum.*

The results of over 100,000 punctures are given. An investigation of the effect of temperature indicates that none of these punctures occurred according to the thermal theories of breakdown. Tests to determine the effect of electrode area are also described. It is shown that statistical theory can be applied to the results with some success. The standard deviation of the breakdown values is a measure of the inherent variability of the material, and thus gives promise of value in the specification of insulation.

* * * * *

THE pyroelectric theory of insulation breakdown, introduced in 1922 by K. W. Wagner[1] and independently by Steinmetz and Hayden[2], gave a great impetus to the study of the failure of solid dielectrics. Several investigators, particularly Dreyfus[3], Kármán[4] and Rogowski[5], have added to the theory, while others such as Mündel[17], Rochow[18] and Gabler[19], have attempted experimental verification.

The experimental results to date are, however, meager and unsatisfactory, and constitute a serious barrier in the way of further progress. One reason is the difficulty of getting consistent values of puncture voltage. Breakdown measurements are inherently more erratic than either resistivity or dielectric loss measurements. Puncture depends evidently only on the strength of the weakest path through the dielectric, while the measurement of other quantities is more or less an integration process giving an average of all the elementary paths through the insulator. The only solution of the difficulty seems to be to take the average of a great number of readings.

It was our purpose to build an automatic machine to make these breakdown tests in large numbers under accurately controlled conditions and with the minimum of manual labor. Such an oufit was completed at the Massachusetts Institute of Technology in the fall of 1925†. In the school year of 1925-26, 130 runs were made with a total of over 100,000 readings.

The apparatus will test any thin sheet material obtainable in long strips. A piece 1¼ in. wide and about 80 ft. long is sufficient for a day's run of 1000 punctures. The outfit consists essentially of a pair of electrodes, an insulation feed mechanism, and suitable means of automatically raising the voltage and recording the value at which breakdown occurs. The feed mechanism operates after each puncture, bringing a fresh length of insulation between the electrodes. A 4000-volt, d-c. generator is used for the tests, the voltage being raised at a constant rate by a motor-driven rheostat in the field circuit. The value at which puncture occurs is recorded by an ordinary graphic voltmeter.

That accurate results are obtainable is shown by the results of 16,000 punctures made on thin condenser paper, Fig. 12. The probable error of the daily average is 3.6 volts. Therefore, it may be said that with this material under the condition of the tests, *the daily average is correct to ± 3.6 volts, or less than 1 per cent.* An investigation of the sources of error has led us to

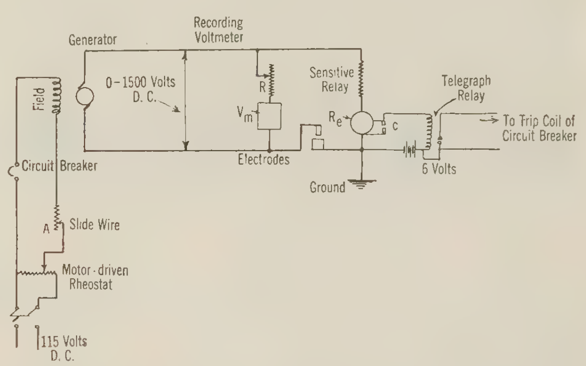

FIG. 1—SIMPLIFIED DIAGRAM OF CONNECTIONS

believe that nearly all the variation from hour to hour and from day to day is caused by variations in the paper. The accuracy of the results depends, of course, on the number of readings averaged for each point, and upon the variability of the material. With a more uniform material than paper, still more accurate results could be obtained with the same number of readings.

APPARATUS

Diagram of Connections. A simplified diagram of connections is shown in Fig. 1. All tests are made with direct current furnished by a 4000-volt generator. The field of this machine is separately excited from the 115-volt mains, a motor-driven rheostat being used to vary the voltage automatically. This rheostat is driven by a small synchronous motor, and twice a minute raises the generator voltage at a uniform rate from zero to a value somewhat above the breakdown point of the insulation.

This voltage is applied to the material between the electrodes. When puncture occurs, the rush of current operates the relay, R_e, which trips the breaker in the field circuit of the generator. Across the line is also

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1. For all references, see Bibliography in complete copy.

†The authors wish to express their appreciation of the work of Mr. L. M. Dawes of the Elec. Eng. Dept., under whose direction most of the apparatus was constructed. Thanks are also due to the General Electric Co. for its help in the early stages of the work.

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connected the recording voltmeter, $V\,m$. Every time the voltage rises, this voltmeter draws a line across its chart. The pointer continues to move slowly across the chart until breakdown occurs, when it falls back to zero due to the opening of the circuit breaker. The length of line is thus a measure of the breakdown voltage.

Just before the motor-driven rheostat is ready to start raising the voltage again, contacts on its rotor close and operate the feed mechanism. This pulls a fresh piece of insulation under the electrodes. At the same time, the circuit breaker closing coil is energized. The voltage is then built up as before. The cycle of operations is thus as follows: Voltage is raised slowly, puncture occurs tripping circuit breaker, feed mechanism operates, circuit breaker closes, voltage starts rising again. The cycle is repeated indefinitely.

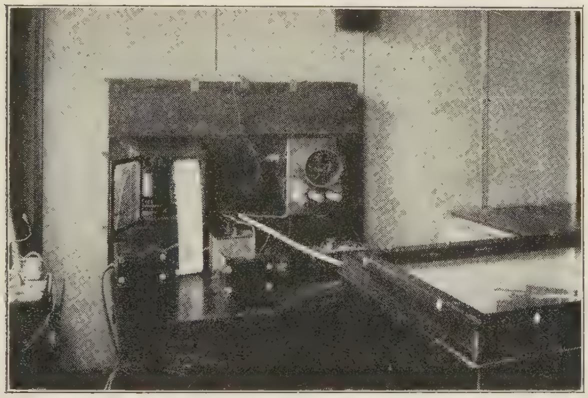

Fig. 2—Instrument Board

Fig. 2 shows some of the apparatus. On the left of the board is the recording voltmeter. At the right is the sensitive relay. A series protective resistance of about 50,000 ohms is seen directly below the relay. The large box in the right foreground is called the constant humidity box.

Procedure

All the tests were made on General Electric condenser tissue 0.0005 in. thick. This was a good grade of rag stock, and was not varnished, oiled, or otherwise treated. This material was used, not because of any special interest in its properties, but because it seemed to offer a cheap and fairly good material which could be obtained in long strips. All tests were made with paper from a single roll.

From 800 to 1000 punctures were made in a day. The resulting voltmeter chart consisted of a large number of lines ruled by the voltmeter, the length of each line representing the voltage at which one puncture occurred. A portion of such a chart is shown in Fig. 6. The lines are ruled 40 to the inch. The daily average is obtained by adding all these puncture voltages on a calculating machine and dividing by the number of readings. Hourly averages are also sometimes used, each consisting of the average of the 100 to 120 readings taken in one hour.

Results

Effect of Temperature. It seems reasonable to expect the thermal theories to apply in a great number of cases of breakdown. It seems equally likely, however, that the theories will fail in other cases such as sudden application of voltage, very low ambient temperatures, or extremely thin materials. In such cases there is little possibility of progressive heating of some path through the insulation, and breakdown must be of a different nature. There appear to be, then, at least two mechanisms of breakdown† which we will call "thermal" breakdown and "disruptive" breakdown. The question then arises as to the limits of applicability of each theory. This is a subject for experimental investigation.

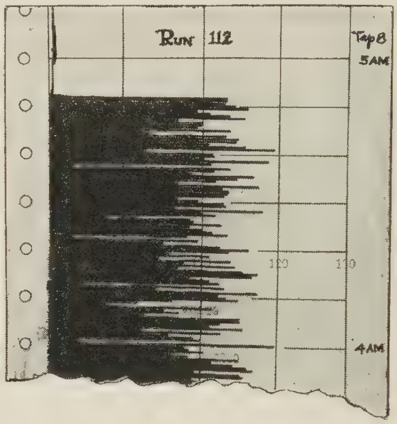

Fig. 6—Sample Voltmeter Chart

Range of scale = 325-700 volts using voltmeter tap No. 8

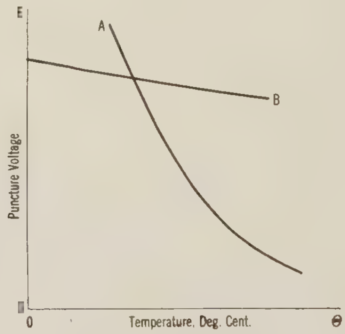

Fig. 7—Probable Shapes of $E - \theta$ Curves

A—Predicted by thermal theories of breakdown

B—Probable shape for distruptive breakdown

If puncture voltage be plotted against temperature, the thermal theories predict an exponential curve A, Fig. 7. Purely disruptive punctures, on the other hand, would probably be nearly independent of the tempera-

†Hayden and Steinmetz, Bibliography No. 8, discuss several possible mechanisms of breakdown. In this connection, Rogowski says: "The opinion that breakdown is caused solely by heating must be abandoned in the case of thin plates, low temperatures, and sudden applications of voltage. On the other hand it may be correct for thick plates, high initial temperatures, and sufficiently long voltage applications; though a decisive verdict is not possible at present due to lack of suitable experimental material."

ture, as in the curve B. It seems likely, therefore, that if a curve were obtained for any material over a wide enough range of temperatures, thermal breakdowns would occur in part of the range and disruptive breakdowns in the remainder. A combination of A and B would result. Such a curve would prove the existence of both kinds of punctures, and might lead to some criterion by which the transition point could be predetermined.

The results obtained are shown in Fig. 8. The temperature was varied from − 2 deg. to + 130 deg. cent., as wide a range as could be conveniently obtained. Each point represents a daily average of from 800 to 1000

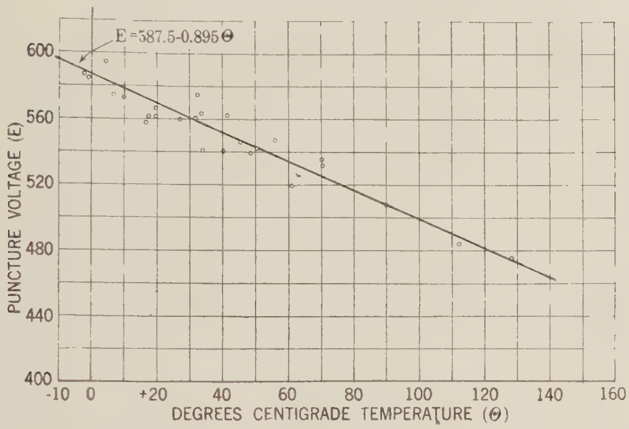

Fig. 8—Breakdown Voltage As a Function of Temperature

Runs 103-130
Electrode No. 3
Electrode pressure = 210 lb. per in.^{2}
Relay protective resistance = 30×10^3 to 56×10^3 ohms
Voltage raised at 1800 volts per min.
G. E. condenser paper baked in vacuum for 8 hours at 72 degrees centigrade before each test
Each point represents the average of from 500-1000 readings

readings. It will be noted that a rise in temperature of 100 deg. cent. causes a diminution in puncture voltage of only 15 per cent.

The curve appears to be of the form B rather than A.* Further analysis given in Appendix A leads to the same conclusion; namely *none of the punctures obtained in these tests occurred according to the thermal theories of breakdown.* This is probably due to the very thin material used and the excellent heat-transmitting properties of the electrodes‡. Further tests are now in progress with thicker materials with which it is hoped to obtain curves of both the A and B types.

Effect of Electrode Area. Considerable work has been done in the past regarding the effect of electrode size. In 1913, Mr. F. M. Farmer[20] presented the results of tests on varnished cambric and hard rubber with electrodes of various sizes. Mr. Milnor[44] showed that, if we consider the insulation to be non-homogeneous, each elementary area between the electrodes having its individual value of dielectric strength, and if we assume further that these values are distributed according to the normal form of probability curve and that puncture occurs at the weakest point, then the breakdown voltage should be

$$E = C_1 - C_2 \log A$$

A is the area of the electrodes and C_1 and C_2 are constants. This is known as the "weak-spot" theory. Farmer's curves were of this form. The experiments of Gewecke and Krukowski[21] also seem to support the weak-spot theory. Further work by G. Y. Fong[23] and

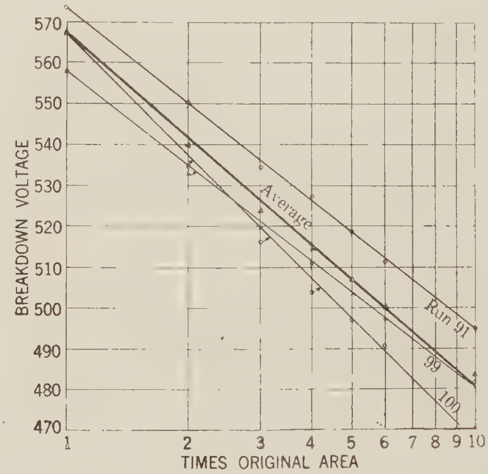

Fig. 9—Breakdown Voltage As a Function of Electrode Area

Electrode No. 1

Kennelly and Wiseman,[24] however, have cast some doubt on the validity of the theory, and nothing really conclusive seems to have been decided.

In connection with an investigation of the various factors which might have caused errors in the $E - \theta$ curve, some runs were made to determine the effect of electrode area. While the evidence is not conclusive, it seems to support the weak-spot theory.

If the weak-spot theory is correct, the breakdown voltage obtained with large electrodes of area $n\,A$ should be the same as the lowest value obtained in n consecutive tests made with electrodes of area A. In other words, puncture should occur at a certain voltage corresponding to the weakest spot in a given area, regardless of whether this area is tested all at one time by the use of large electrodes, or is tested one section at a time with small electrodes. Thus if a large number of tests is available, using one size of electrodes, the puncture voltage for electrodes of twice this area should be obtainable in the following way: Consider the results in groups of two, discard the higher value in each case, and take a new average of the remaining figures. Similarly, the breakdown voltage for three times the original area should be obtainable by dividing the readings into groups of three and averaging the lowest values of each group.

*In accordance with the Joffe theory of breakdown which has recently appeared, our curve is a measure of the number of free ions existing in the material at various temperatures.

‡See also Appendix B. Since our paper was written, some very valuable work by Inge, Semenoff and Walther has been published[52]. $E - \theta$ curves are obtained showing a decided break where the mechanism of breakdown changed from the disruptive to the thermal type.

This was done in the case of Electrode No. 1 as shown in Fig. 9. The area of this electrode was taken as unity for convenience. It will be noted that the result is very accurately of the form

$$E = C_1 - C_2 \log A$$

as was predicted by Milnor. Our tests, therefore, support his proof. His assumption of a normal distribution of puncture voltages (an assumption which at that time had not experimental verification) is also verified by our tests.*

Similar analyses were made with electrodes of twice and four times the area. The results† are shown in Fig. 10. To be a perfect check of the weak-spot theory, the three curves should coincide. Though all curves have practically the same slope, No. 2 is about 2 per cent higher and No. 1 about 2 per cent lower than No. 3. Probability theory shows that this is too large a discrepancy to be due entirely to random variations in the paper. It is most likely caused by a "seasoning" action of the electrode faces, an effect which unfortunately was not discovered until after these runs were finished.‡ It is also possible that some thermal or other effects are present which are ignored by the weak-spot theory. The tests, however, indicate that the theory is at least approximately correct.

The Standard Deviation. Fig. 11 shows the frequency distribution for a day's run. This was obtained by counting the number of readings falling in each 10-volt interval. The smooth curve is the probability curve having the equation—,

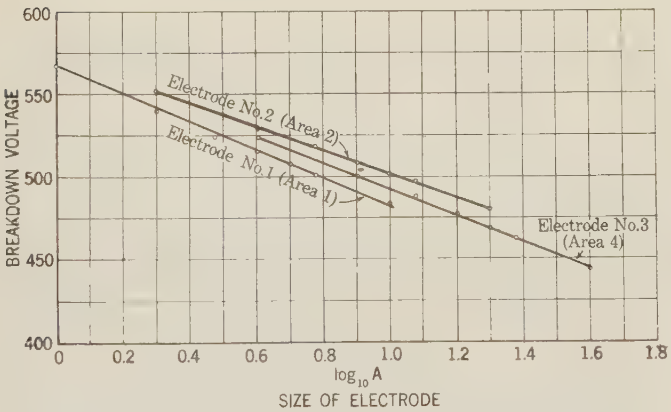

Fig. 10—Breakdown Voltage As a Function of Electrode Area

Average of 8808 readings
Electrodes Nos. 1, 2, 3
Electrode pressure = 210 − 850 lb. per in.^{2}
Relay protective resistance = 56 $\times 10^3$ ohms
Voltage raised at 1800 volts per min.
G. E. condenser paper baked in vacuum for 8 hrs. at 72 deg. cent. before each test

$$y = \frac{1}{\sigma\sqrt{2\pi}}\,\epsilon^{-\frac{x^2}{2\sigma^2}}$$

It will be noted that the points of our frequency distribution fall fairly well on this curve, showing that the distribution is of the normal form such as is obtained for the variations of any quantity governed purely by chance§. Distributions obtained on other runs are very similar to the one shown. The highest point of the curve is, of course, at the arithmetic average of all the readings, and thus is the most probable voltage of breakdown.

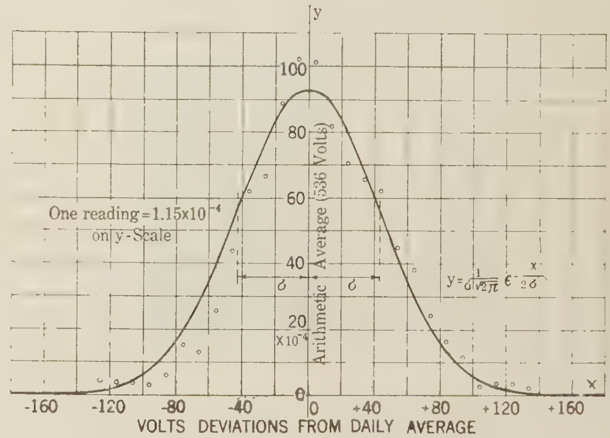

Fig. 11—Typical Probability Curve

Run 108
$\sigma = 43.1$ volts

$$\frac{1}{\sigma\sqrt{2\pi}} = 92.6 \times 10^4$$

The constant σ in the above equation is called the *standard deviation* or *dispersion*. It is a very important constant in statistical work, since it completely specifies the distribution, and thus takes the place of a mass of data. The standard deviation was obtained from the puncture voltage readings by the use of the equation

$$\sigma = \sqrt{\frac{\Sigma\,(\delta)^2}{n}}$$

where $\Sigma\,(\delta)^2$ is the sum of the squares of the deviations from the mean and n is the number of readings. In this case, $\sigma = 43.1$ volts. A more uniform and homogeneous material would have a more peaked curve and therefore a smaller value of sigma. A more variable material would have a larger sigma. Thus the constant σ is a measure of the inherent variability of the material.*

It is believed that the standard deviation will be of practical importance in future insulation engineering. Sigma is a constant of the material, just as important in its way as puncture voltage. The puncture voltage indicates the average value at which breakdown occurs; the standard deviation tells how much variation there

*See Fig. 11.

†All tests were made at a temperature of 48 deg. cent., humidity of 0.4 to 4 per cent, and a voltage rise of 1800 volts per min.

‡See "Effect of Polishing Electrodes."

§See, for instance, Bibliography, 44-50.

*It also includes of course, the accidental errors of measurement.

will be from sample to sample. By knowing both these constants, the insulation designer can put his work on a much firmer foundation than would otherwise be possible. The constant should also be of use in the specification of insulating materials. The variability of the material bought by large cable or condenser manufacturers, for instance, is of the utmost importance to them. By specifying σ and keeping it up to standard by tests made on samples from each batch received, the manufacturer would eliminate one of the variables which tend to produce a non-uniform product.

Precision of Results. As previously noted, Fig. 12 shows the results of 16,000 punctures made under the same conditions. The temperature was kept at 40 deg. cent., the humidity was between 0.2 and 0.4 per cent, and the electrode No. 0 was used throughout. Each point represents an hourly average of between 100 and 120 readings. The ordinates are the deviations of the hourly averages from the average of the day in which they occurred. The abscissas are merely consecutive hours of run. With the exception of the first run, the data do not appear to have any decided trend, either up or down, but seem to be purely random variations such as would be expected from variations in the paper itself.

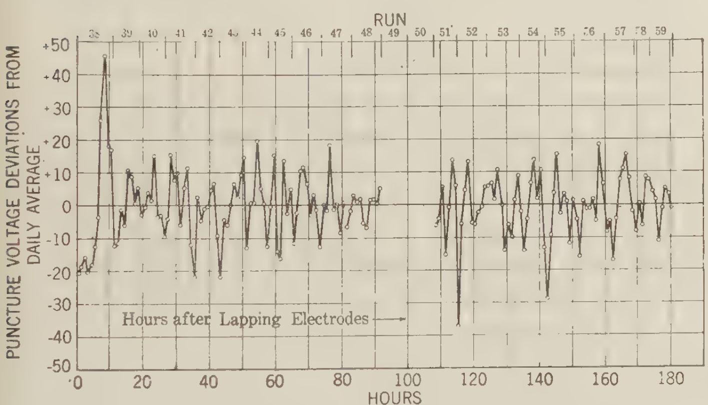

FIG. 12—VOLTAGE DEVIATIONS, RUNS 38-60

(Hourly averages minus daily average)

That the variations are random and follow the normal law is shown by Fig. 13. The points give the frequency distribution of these hourly averages. The smooth curve is the theoretical probability curve. The points fit the curve about as well as could be expected with such a small number of data, only 150 points. The next curve, Fig. 14, shows the deviations of the daily averages from the average of the eighteen runs from No. 39 to 59, inclusive*.

A statistical analysis was made of all the data, Appendix C. The actual values of σ are as follows: For the individual reading, 40 volts; for the hourly average, 9.19 volts; for the daily average, 5.3 volts. Comparison of the hourly and daily sigmas with the corresponding values predicted from the σ of the individual readings by probability theory, shows that in both cases the actual values are too high. The discrepancy of the daily value is, however, not much greater than that for the hourly sigma. This would seem to indicate that the unavoidable changes in humidity and baking (variations which did not occur from hour to hour) were not responsible for the variations in the daily average. It is thought that both hourly and daily variations are due principally to inherent variations in the paper itself.

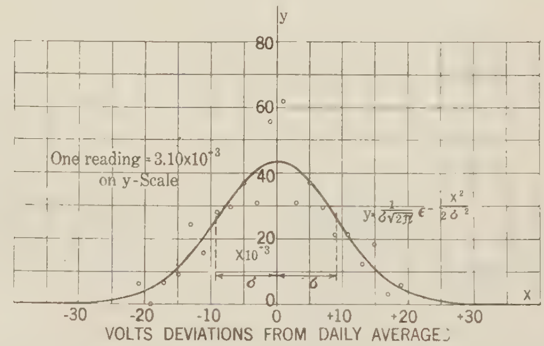

FIG. 13—PROBABILITY CURVE OF HOURLY AVERAGES, RUNS 39-60

σ = 9.19 volts

$$\frac{1}{\sigma\sqrt{2\pi}} = 0.0434$$

Appendix C also shows that the probable error of the daily average is 3.6 volts, and thus the daily average is correct to less than one per cent.† Analysis of the runs used in obtaining the $E - \theta$ curve, Fig. 8, shows a similar situation. The probable error of the daily average in this case is 4.7 volts, giving again an error of less than 1 per cent. Thus the accuracy obtained by the machine is evidently much greater than could have

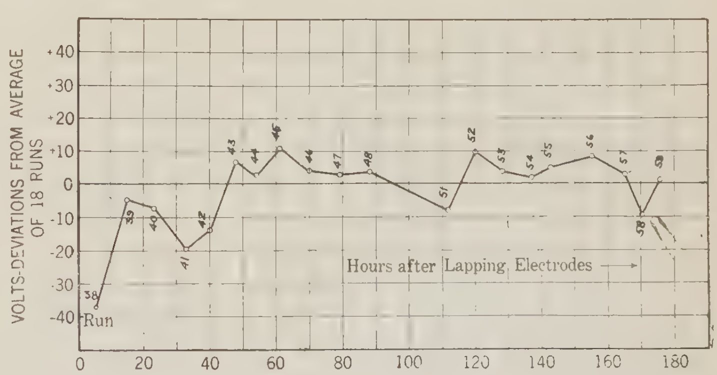

FIG. 14—DEVIATIONS OF DAILY AVERAGES FROM TOTAL AVERAGE OF 18 RUNS

All readings corrected to 30 deg. cent.

*Run 38 was not used because of its low average. This is explained in the next section. Runs 49 and 50 were made, but the hourly averages were not computed.

†This, of course, ignores any constant errors which may have been present in all the tests.

been reached by the usual methods without an undue expenditure of time and labor.

A list was made of all possible sources of error. These included variations in the temperature and time of baking, variations in humidity, electrode size and pressure, rate of voltage rise, value of protective resistance, time which elapsed after polishing the electrodes, voltmeter calibration, and errors in temperature measurement. Nearly all of these factors were investigated over a wider range than would be likely to occur accidentally.

The effect of polishing the electrodes was found to be very considerable, as will be shown later. Too high a protective resistance was also found to have great effect, since it produced sluggish operation of the relay. Care was taken to eliminate both of these errors.‡ The other factors were shown to have very little effect in the limited range through which they might conceivably have varied. It seems unlikely that any of them caused variations of more than 1 or 2 volts. This again goes to show that most of the variation was due to the paper itself.

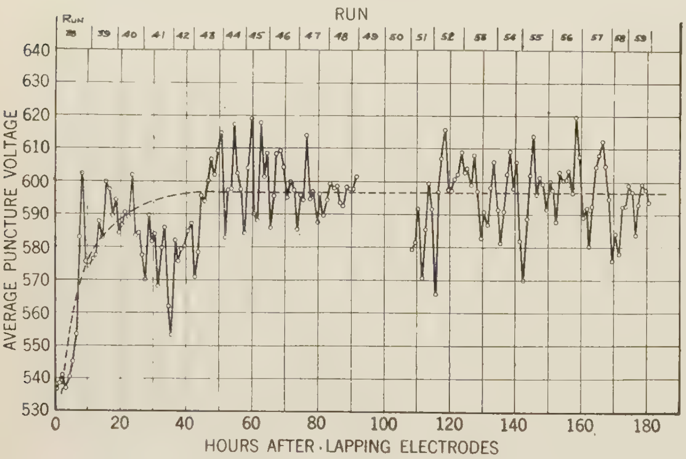

Fig. 15—Hourly Averages, Runs 38-60

All readings corrected to 30 deg. cent.

Dotted curve indicates the upward trend of voltage due to seasoning of the electrodes

Effect of Polishing Electrodes. It has already been noted that the puncture voltage in Run 38 was very low. This is also shown in Fig. 15 where hourly averages are plotted against hours' use of the electrodes after polishing.§ Here the low puncture voltages obtained after polishing are very evident. To make sure that this was not a freak happening, hourly averages were plotted for a number of other runs, and in each case the time of polishing the electrodes was clearly shown by a set of readings lower than those obtained at any other time.

Brass and copper electrodes are commonly used for breakdown tests. It is probable that this phenomenon has been present in most tests, though it appears not to have been noticed before. Evidently if tests are made on the very steep part of the curve, the results will be much more inconsistent than would otherwise be the case. In our tests, it was necessary to discard at least 1000 readings after the electrodes were polished.

The cause of this trouble is not known. Current at breakdown was limited by the protective resistance to such a low value that there was no pitting of the electrodes nor was there any apparent roughening of the surface. One possible explanation is that the puncture produces an insulating coating on the electrode surfaces. Examination of the electrodes shows that each puncture causes a small black mark on the electrodes. These spots distribute themselves fairly evenly over the entire electrode surface. After a day's use, the faces reach a state of more or less uniform blackening, which is not altered much by subsequent runs. If each spot introduces a high resistance in series with the paper below it, puncture will tend to occur at places where there are no spots. This will have the effect of decreasing the effective surface, and will increase the puncture voltage accordingly. After a large number of punctures, the blackening effect will reach a nearly constant value, with like effect on the puncture voltage. Tests are now being made to determine if this effect can be eliminated by the use of a nonoxidizing metal for the electrodes.

Conclusions

A curve of puncture voltage against temperature was obtained for 0.0005-in. condenser paper in the range from − 2 deg. to + 130 deg. cent. The puncture voltage was found to decrease uniformly at about 0.9 volt per deg. cent. rise. Comparison of these data with the thermal theories of breakdown indicates that none of these punctures occurred according to the thermal theories, but were evidently of the disruptive type.

It was found that the puncture voltage measurements were distributed according to the normal law. A set of 8800 readings with different sized electrodes appears to support the weak-spot theory, though the evidence is hardly conclusive.

The standard deviation of the readings was found to be a constant of the material, independent of the electrode area and only slightly affected by temperature and number of readings. It is believed that this constant will be of considerable use in the specification of insulation, since it is a measure of the variability of the material.

It was found that the inherent variability of the paper was not confined to causing variations from reading to reading, but also caused long-time variations from hour to hour and from day to day. This reduces the accuracy of the daily averages below the values predicted by the theory of probability.

An analysis of the results indicates that the variations from hour to hour and from day to day are largely due to variations in the paper itself. An investigation

‡Except in the investigation of electrode area, where the effect of polishing the electrodes was probably of importance.

§The gap at Runs 49 and 50 is due to the fact that hourly averages were not computed for these runs.

was made of the various possible sources of error, and it appears that no one of them could have caused an error of more than one or two volts. The probable error of the results is shown to be less than 1 per cent. This precision is evidently considerably higher than could have been obtained in the ordinary way without a great expenditure of time and labor.

Copper and brass electrodes are commonly used for puncture tests. Our experiments, however, indicate that with such electrodes there is a "seasoning" effect. This produces a marked change in puncture voltage unless the electrodes are cleaned after each puncture or are allowed to reach a steady state before readings are taken. Such a condition was obtained only after about 1000 readings.

Appendix A

Thermal Theory of the $E - \theta$ Curve

According to the thermal theories of breakdown, puncture occurs when

$$\frac{E^2}{\rho} = C, \text{ a constant*}$$

where E = voltage gradient at breakdown,

ρ = resistivity of the weakest path at the temperature of the surroundings, θ.

Physically, this means that for a condition of instability to obtain, it is necessary that the rate of heat generation per unit volume (E^2/ρ) shall reach a certain critical value (C). This value is a constant for a given material. It depends upon the thermal conductivity, the temperature coefficient, and also, in Rogowski's theory, upon the thickness.

If we assume that the resistivity is an exponential function of the temperature

$$\rho = \rho_0 \, \epsilon^{-\gamma\theta}$$

then it is evident that

$$E = \sqrt{C \, \rho_0} \, \epsilon^{-\frac{\gamma}{2}\theta}$$

Thus the γ obtained from resistivity measurements will determine the change of puncture voltage with temperature.

Unfortunately, no resistivity measurements have yet been obtained on the paper used in these experiments. According to the work of J. E. Shrader[30], however,

*According to Wagner, loc. cit., formula 2,

$$\frac{E^2}{\rho} = \frac{k}{\gamma \, \epsilon}$$

k = thermal conductivity,

γ = temperature coefficient of resistivity,

ϵ = 2.71828 . . .

This is based on the assumption that heat flow is radial from a thread into the surrounding insulating material.

Rogowski assumed that heat flowed only into the electrodes, and obtained the result, Rogowski, loc. cit., Formula **11**,

$$\frac{E^2}{\rho} = \frac{8\,k}{\gamma \, D^2}$$

where D is the thickness of the insulation. The only difference is in the constant C.

untreated fish paper has a temperature coefficient of about 0.07. Assuming this value for γ, we find that the puncture voltage at 100 deg. cent. should be

$$E_{100} = 587.5 \, \epsilon^{-\frac{0.07}{2}(100)} = 18 \text{ volts}$$

instead of the 498 volts actually obtained.

If, instead of a straight line, we use an exponential to approximate the data of Fig. 8, we find

$$E = 587.5 \, \epsilon^{-0.0016\theta}$$

The value of γ is thus 0.0032. That such a value is very improbable is shown by the following table:

Authority	Material	γ
J. E. Shrader[30] . . .	Untreated fish paper, vacuum dried	0.07
J. E. Shrader[30] . . .	Untreated fullerboard, vacuum dried	0.07
J. E. Shrader[30] . . .	Paraffined fish paper	0.104
H. H. Poole[29]	Mica	0.051
H. H. Poole[29]	Glass	0.109
E. Mündel[17]	Glass	0.084
Landolt-Bornstein[5]	Glass	0.120
Landolt-Bornstein[5]	Hard rubber	0.023
Landolt-Bornstein[5]	Porcelain	0.084

Appendix B

Some work of E. Mündel[17] has recently come to our attention, and a set of his curves has been replotted in Fig. 16. The material used in the tests was glass 0.4 mm. thick. Two curves, A and B, have been added to

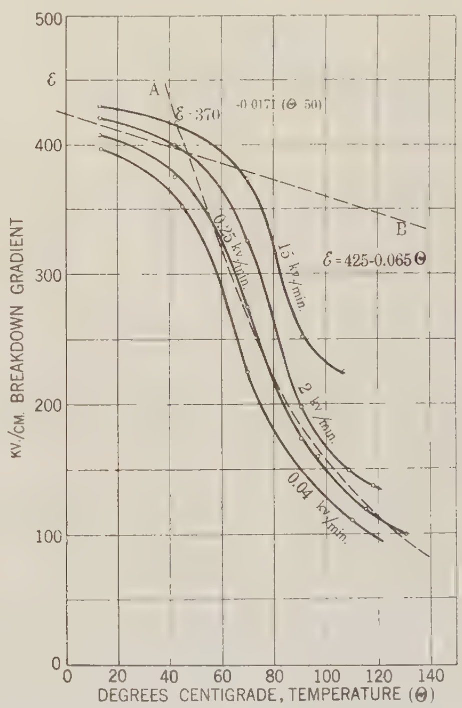

Fig. —16 Puncture of Glass 0.4 Millimeters in Thickness

(From Mundel—*Archiv. f. El.* 15, 1925, p. 338)

Mündel's results. Curve A is an exponential with ($\gamma/2 = 0.0171$). The straight line B falls 15 per cent with 100 deg. cent. increase in temperature just as in Fig. 8.

These curves are a possible explanation of Mündel's results. The part of his curves from 50 deg. upward is evidently caused by thermal breakdowns, while the lower temperature punctures were probably disruptive.

It will be noted that all the curves appear to approach the slope of B as the temperature is descreased, while at the higher temperatures they approximate exponentials about as closely as the usual curves for resistivity do.

The value ($\gamma = 0.034$) from curve A seems to be a little low for glass; see table in Appendix A; but the discrepancy may be due to the fact that the resistivity of most insulating materials is a function of voltage as well as temperature, a fact which is neglected in the thermal theories.

Mündel's results, therefore, indicate the existence of both mechanisms of breakdown and show that the transition point for this particular case is about 50 deg. cent.

Thermal breakdowns are probably obtained in Mündel's tests and not in ours because of the difference in thickness of the two materials, his glass being about 30 times the thickness of our paper. All of our tests are undoubtedly on the straight line far to the left of his curves.

It is evident that for practical purposes, nothing could please the insulation expert more than to be sure that his insulation would operate on curve B rather than A, since its breakdown strength would then decrease so little with temperature. With a more thorough knowledge of insulation, the future engineer may be able to avoid thermal breakdowns altogether.

Appendix C

The following analysis was made:

Total readings, Runs 39-59, inclusive, = 16,505
Total hours . . . . = 154
Total days . . . . = 19

Av. hrs. per day = 8.11
Av. rdgs. per day = 869
Av. rdgs. per hr. = 107

From individual readings:

σ of one reading = 40 volts

$$\sigma \text{ of hourly aver.} = \frac{40}{\sqrt{107}} = 3.86 \text{ volts}$$

$$\sigma \text{ of daily aver.} = \frac{40}{\sqrt{869}} = 1.35 \text{ volts}$$

$$\sigma \text{ of total} = \frac{40}{\sqrt{16505}} = 0.31 \text{ volt}$$

From hourly averages:

σ of hourly aver. . . . = 9.19 volts

$$\sigma \text{ of daily aver.} \quad \frac{9.19}{\sqrt{8.11}} = 3.22 \text{ volts}$$

$$\sigma \text{ of total } \frac{9.19}{\sqrt{154}} \quad . \quad . \quad = 0.74 \text{ volt}$$

From daily averages:

σ of daily aver. . . . = 5.30 volts

$$\sigma \text{ of total} = \frac{5.30}{\sqrt{19}} \quad . \quad . \quad = 1.22 \text{ volts}$$

Probable error of daily aver. $= 5.30 \times 0.6745 = 3.6$ volts
Probable error of total $= 1.22 \times 0.6745 = 0.82$.

These results can be tabulated as follows:

STANDARD DEVIATION

	Individ. rdg.	Hourly	Daily	Total	Daily σ / σ by Ind. rdgs.
By indiv. rdgs.........	40_v	3.86	1.35	0.31	1.0
By hourly aver........		9.19	3.22	0.74	2.4
By daily aver.........			5.30	1.22	3.9

AIR TRAVELERS CAN TELEPHONE HOME

Passengers flying across the continent—or even around the world—in airplanes may very well call up their friends at home by the combined use of radio and telephone. This possibility was well demonstrated at the recent war show in Chicago where radio conversations of various sorts were maintained between several planes, land stations and the telephone system in Chicago.

During the show, which took place in and over a stadium in Chicago, airplanes circling overhead executed commands given by an officer on the ground. His voice was heard by the audience throughout the stadium by a public address system of loud speakers and amplifiers as he gave directions by radio telephone to the fliers. The audience then could watch the airmen immediately do as the voice commanded.

Preliminary to the show, an airman flying from Rantoul, Ill., to Chicago, put in a telephone call for a friend in a Chicago hotel and conversed with him. Also two planes flying in various parts of the middle West carried on radio conversations which were picked up and broadcast by one or two broadcasting stations so that thousands of people sat in their homes and heard the odd communication going on.

A line of landing fields for aviators running 200 miles from Cheyenne, Wyo. to Pueblo, Col. is about to be built. These areas at 30-mile intervals will each be illuminated by 31 electric floodlights. Between them, marking the course, will be a line of electric searchlights 25 miles apart. Blinker lights along the way will be operated by sun dials going on and off with night and day.

Railway cars that run under their own electric power generated on board by oil engines are appearing on many American Railways for branch line and local passenger service. Seven railroad companies including the Alaskan Government Railway have ordered cars built. In Alaska one of them will operate from Seward through Anchorage to Fairbanks, 945 miles of rough travel, making a round trip in four days.

A Carrier-Current Pilot System
of Transmission Line Protection

A. S. FITZGERALD[1]

Introduction

THE increasing complexity of modern transmission networks presents many difficult problems in connection with the design and application of protective relays.

On the larger systems, the use of increased time delay may be inadmissible on account of the difficulties met with in maintaining stable operation. Rather, there is a tendency in the direction of reduction in the time of operation of relays.

Thus, there is a growing interest in differential methods of protection; that is, in systems in which comparison is made between currents which under normal conditions are necessarily equivalent. These have the advantage of not being dependent upon the performance of relays in other circuits for their selective action.

The simplest form of differential protective arrangement consists of a circuit embracing a portion of a power system, (such as a generator winding or transmission line), and registering any difference which may occur between the current entering or leaving the section protected.

Such arrangements offer very definite advantages over all other selective relay schemes, in that each section of the network so protected is a unit in itself and it is not affected by any other protective measure, nor by any alterations in the network arrangement. Thus no changes in the relay setting are necessary nor are these, in general, influenced by the direction of flow of power or fault current, nor by the settings of relays on connecting lines, as is the case with time delay overload protection. Moreover, in differential systems, faults may be cleared with a minimum loss of time.

These advantages are so marked that the differential system of protection is employed almost universally for the protection of generator windings, and similar applications where the extent of the circuit protected is a matter of yards rather than miles. For the protection of lines, however, the cost of the special pilot conductors has greatly restricted the application of this type of relay system, and it is not in general use in this country except for short distances or where there are so many sections in series that time delay methods are not desirable.

The success that has attended the use of differential pilot wire schemes in other countries, where the length of lines is less, indicates the desirability of a means of furnishing a similar service without the necessity of special conductors.

1. Radio Engineering Dept., General Electric Co.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Calif., September 13-16, 1927,

Carrier Currents

The term carrier current is employed as descriptive of a-c. energy generated at frequencies which lie, roughly, between 10 and 200 kilocycles. At these frequencies, the transmission of electrical energy exhibits special characteristics due to which it is possible to superpose carrier-current-control circuits on transmission lines or cables.

Carrier current is conducted more or less freely by straight conductors, and is restricted thereto by breaks or open circuits, except in so far as capacity paths are provided by parallel lines situated in close proximity. Carrier current may be employed for control systems because circuits may be provided which will conduct the carrier current but which will not effectively pass 60-cycle power current, and by means of which the carrier current may be introduced into, or taken out of, a power system.

Conversely, the flow of carrier current can be restricted within certain specified limits by circuits which provide a high impedance to carrier current but do not affect power currents.

Carrier current energy is commonly generated by means of three-electrode tube oscillators.

Requirements of a Protective System

A protective scheme suitable for association with carrier current operation and desirable from commercial and operating aspects, will preferably include the following features:

1. The employment of potential transformers will be avoided.

2. The scheme should not require any definitely quantitative function on the part of the carrier apparatus since there may be variations in attenuation.

3. There should be no apparatus installed as part of the protective system which in itself represents an extension of the liability to trouble of the circuit protected. Current transformers of high safety factor, preferably of the bushing type, should be used. The carrier-current coupling equipment should be of the most reliable form available.

4. The equipment so far as possible, should be entirely current operated; that is, its operating power should be derived directly from the fault current.

5. Failure of the carrier-current apparatus should not render it possible for a fault to remain on the line thus disturbing the whole power system. Rather such a defect should advertise its presence by causing only the individual line to trip unnecessarily if overloaded.

6. The system should be suitable without modifica-

tion for installation at any point in a network irrespective of possible direction of flow of fault current, etc.

7. It should be possible to check the carrier-current equipment at any time without interfering with service.

8. In view of the fact that a restricted range of frequency is assigned to control systems, only one frequency per line protected should be used.

General Principles

In its simplest form, differential protection consists of the installation of two current transformers at each extremity of the circuit embraced, one to receive the current entering the section, and the other, that leaving it. The secondaries are either connected in opposition and in series with one or more relays; or more usually connection is made so that the currents normally circulate, in which case the relays are connected across equipotential points. In either arrangement, the relays, normally, should receive no current, but on the occurrence of a fault, which will be a difference between the entering and leaving currents, a corresponding difference will appear in the relays. Numerous refinements and variations of this principle have been evolved in order to overcome difficulties in balancing and to render the apparatus immune from tripping on heavy "through" currents.

It will be perceived that the function of the pilot conductors is to furnish one end of the line with a sample of the current at the other end, in order to provide the relays with means of discriminating between sound and faulty conditions.

It is not, however, desirable to employ exactly similar principles when carrier current is to be used in place of a pilot line. This is due to the fact that carrier current is usually transmitted by means of resonant circuits. Because of this, and other causes, it is not always possible to achieve exact numerical ratio between the carrier current transmitted from one point and that received at another. Thus, it is preferable to avoid an arrangement in which fault conditions are indicated by a difference between the magnitude of the currents concerned.

A transmission line will be equipped with a circuit breaker at each end and with relays designed to trip the breakers automatically in the event of abnormal currents being carried by the line. The relays may operate on overcurrent, ground current, or may be power-directional. Such relays will correctly indicate abnormal conditions, but, in the general case, do not, by themselves, distinguish between a fault on the line—when we want both switches to trip—and a fault elsewhere, when we wish to avoid interrupting the line.

In order to accomplish this, we must know at each end of the line what is happening at the other end, and it is for this purpose that we employ the carrier-current system.

In ring systems, or networks, a fault generally not only causes a difference in the magnitude of currents entering and leaving the faulty line, but also sets up a difference in direction.

One method of carrier-current protection would be to employ power directional relays at each end and to use the carrier to furnish at one end an indication of the position of the relay contact at the other. Such an arrangement would be quite practical, but a system independent of line potential is to be preferred.

Principle of Operation

The effect of a fault on the normal direction is the feature employed to discriminate. In order, however, to avoid potential excitation, the direction of power is not used, but instead, the instantaneous direction of current. This is done in the following way:

The carrier is not used to trip the circuit breakers when the line itself suffers a fault. If this were done, we could not be sure of proper operation if the line should be connected to a source at one end only; or if the line should break in such a way as to bring about

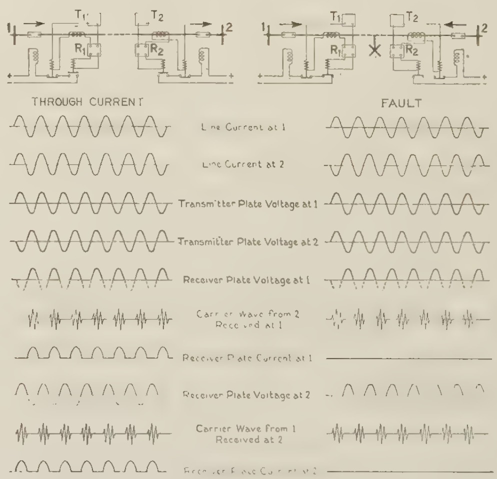

Fig. 1—Principle of Operation

this condition. Moreover, the carrier channel may be interrupted by the fault.

Thus, at each end, overcurrent relays are installed and connected to the oil-switch trip circuit. If the instantaneous currents at each end of the line have the same direction, indicating that the line itself is sound, a carrier signal is received preventing the overcurrent relays from tripping the circuit breakers. This looks after the stub feed, or broken line condition.

If a three-electrode tube oscillator be operated from an a-c. plate voltage, it will oscillate intermittently during those half cycles only when the plate is positive.

In a similar way a bias detector may be supplied with an a-c. plate voltage. It will be inoperative during the half cycles when the plate is negative, but during the positive half cycles, if the grid potential permits, plate current may flow. The grid will be excited from a source of 180 deg. out of phase with the plate voltage so that normally there will be no plate current,

the grid being negative when the plate is positive. If there be impressed on the grid, an additional voltage of carrier frequency, a rectified current may be caused to flow in the plate circuit; but this can occur only during a positive half cycle. Thus, we may have a transmitter sending during alternate half cycles and a receiver capable of receiving only during the intervening half cycles. A relay may be placed in the plate circuit of the receiver tube; this will operate when carrier is received.

Fig. 1 shows, in an elementary manner, how these features may be arranged to furnish the desired result. The diagram represents a transmission line having a circuit breaker and over-current relay at each end. The two ends of the line are designated as "1" and "2" respectively. Carrier-current transmitters T_1 and T_2, at each end, together with receivers R_1 and R_2, are excited from current transformer secondaries. When carrier is received, the receiver relays open the trip circuits and prevent the opening of breakers. The equipment at each end is the same except that, as shown, one of the current transformer secondaries is reversed.

The left hand series of diagrams refers to the case of a sound line which may be supposed to be carrying excess current to a point beyond the bus. It will be seen from the diagram that the primary currents are identical, whereas the plate voltages of the transmitters, which are derived from the current transformer secondaries, are of opposite polarity. The receiver-plate voltages at each end are reversed in respect of the adjacent transmitters. Thus the receiver voltages are also 180 deg. displaced from each other. Each receiver, therefore, is inoperative during the half cycle occupied by the transmission from the transmitter at the same end, and cannot receive from the latter.

Referring now to the transmitter-plate voltages at opposite ends, as shown in the left hand diagram, it can be seen that the positive half cycles occur alternately. Thus the two transmitters, oscillating intermittently, send out pulses of carrier in alternate sequence. The positive half cycles of the receiver-plate voltage are shown in full lines and the negative half cycles, when the receivers are inoperative, are shown in broken lines.

Therefore R_1 is inoperative while T_1 is sending, but can receive from T_2. Likewise R_2 can receive from T_1 but not from T_2. In the case illustrated by the left hand series of diagrams, both receivers are operated and the receiver relays open the trip circuit and thus prevent the over-current relays from tripping the circuit breakers.

The right hand series of curves shows the conditions when there is a short circuit on the line. In this case both the transmitters are sending simultaneously during which period neither of the receivers are able to receive. When both the receivers are operative neither of the transmitters are sending. Thus the receiver relays are not opened and the line is tripped by the over-current relays at each end. The operation of the system, therefore, is such that if a current enters at one end, that end will be opened automatically unless the current is "registered out" at the other end, which is an indication that the line is sound. If a fault be fed from one end only, the transmitter at the other end will not be excited by the current transformer and will not transmit. The fault will therefore be cleared, at the end from which it is supplied, by the over-current relay.

A unique feature of this arrangement is the fact that it is possible to send and receive in both directions at the same time and at the same carrier current frequency. Thus, only a single frequency is required instead of two. This is a distinct advantage if a number of lines is to be protected by this method, and one which will become more evident as the use of carrier current for purposes of communication and control becomes more prevalent.

Single-Phase Circuit

The actual arrangements employed will now be more readily understood. Fig. 2 shows a complete diagram of the system. With a view to simplicity, only a single-phase line is given in the first instance, and the

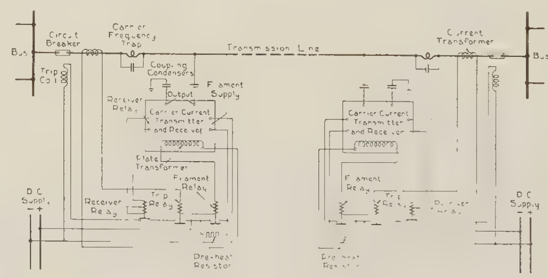

Fig. 2 -Diagram of Connections—Single Phase

carrier current apparatus is not shown in detail. It will be seen that the current transformer is connected in series with the primary winding of the plate transformer and two over-current relays, one of which completes the trip circuit and the other energizes the tube filaments. The former is furnished with a slight, definite, time delay; the latter is instantaneous. A preheating resistance may be connected across the contacts of the filament relay if desired. If the filament be run continuously at reduced voltage, it will have little effect on the life of the tube, but the time taken to raise the filament to full operating temperature will be substantially reduced. If this be done, the time delay of the trip relay need not exceed one-half second. Without preheat, a full second might be necessary.

The trip relay will be set to pick up at a current slightly higher than the filament relay, in order to insure both filament relays closing before either trip relay picks up. The filament relays will be set to operate at a current somewhat exceeding the normal load on the line and not less than that at which the current transformers furnish sufficient plate voltage to operate the transmitting and receiving tubes.

Thus, when an overload occurs on the transmission line, the filament relay first picks up, closing its contacts which connect the filament supply to the vacuum tubes. Within the brief period, necessary for the filaments to reach operating temperature, the carrier-current equipment is fully in operation.

The receiving tube controls a polarized relay, the contacts of which are normally closed. When the carrier wave is transmitted during those half cycles which indicate that the over-current is not due to a fault on the line protected, the receiver tube energizes this relay. Thus, at both ends of the line, the trip circuit is opened and the subsequent closing of the contacts of the trip relays immediately afterwards does not open the circuit breakers.

If, on the other hand the fault should be on the line itself, either the carrier does not reach the receiver, or if it is received, does not affect the receiver because it is transmitted, during the half cycles when the receiver is inoperative. The result is the same in either case; the receiver relay remains closed and when the trip relays close their contacts, the trip circuit is completed and the line disconnected.

It will be noted that the line has positive over-current protection under all conditions except when there is a definite indication that it is sound.

Carrier-Current Trap

An important point in the operation of this system is the affect on the channel of reference of faults. While the principle adopted has followed closely that of wired differential schemes, and the general effect of faults will be viewed from similar aspects, certain differences, due to the use of carrier, are of interest.

The occurrence of a fault may or may not lead to the interruption of the channel of reference; that is, the effective transmission and reception of the carrier wave. Assuming a simple coupling, the carrier will be stopped by a broken line, or a short circuit between the phases to which the carrier is coupled, on the section protected. A similar short circuit outside the protected zone may also have the same effect. Thus, it is necessary to provide between the point of coupling and the bus, a trap circuit for carrier. This prevents short circuits, anywhere but on the section protected, from interrupting the carrier. This trap circuit takes the form of a lightning arrester coil tuned, by means of a condenser, to the frequency of the carrier circuit. The condenser is mounted directly on the choke coil. It is made in the form of an assembly of several dissimilar capacities brought out to terminals in such a way that a large number of combinations may be obtained. In this way, the trap may be tuned to any one of a number of available frequencies. The condenser is arranged to be readily removed from the coil for this purpose.

The complete trap with the condenser in position is shown in Fig. 3. Fig. 4 shows the condenser dismantled for setting to the desired frequency. The condenser shown has three sections and can be set for 17 frequencies ranging from 40 to 120 kilocycles.

The complete connections for both the relay and carrier current circuits, at one end only, are shown in Fig. 5. Two secondary windings on the plate transformer are required to operate the carrier transmitter and receiver. The transmitter is of conventional form, having one master oscillator tube and one power amplifier, a suitable tap being furnished for the lower voltage required by the oscillator. The receiver is an ordinary bias detector, the negative voltage applied to the grid being derived from a tap to the transmitter winding, since this is of opposite polarity, at an instant, from that of the receiver plate winding.

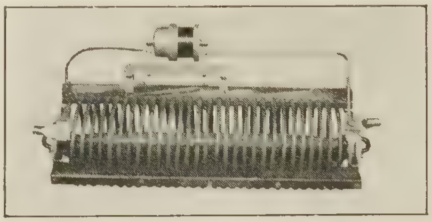

Fig. 3—Carrier-Current Trap

Fig. 4—Carrier-Current Trap Condenser

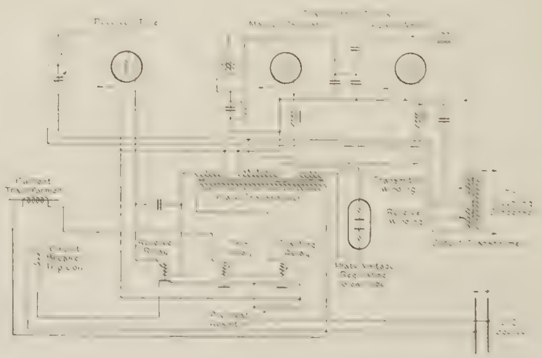

Fig. 5—Carrier-Current Transmitter and Receiver

Plate Voltage Regulation

One of the principal features of any protective relay system is the extreme range of current value over which it must operate. The apparatus should preferably be capable of functioning with currents not greatly exceeding normal load; yet it must sustain without damage, and work properly at the heaviest short-circuit current which the power system can furnish. In

extreme cases, twenty times normal load may be met with.

Since the transmitter and receiver plate supplies are furnished by the current transformer, it is evident that a means must be found for providing a more or less constant voltage over this range of excitation. Vacuum tubes of the type used in carrier-current circuits cannot operate satisfactorily over a voltage range of more than three to one. The problem of extending this range to that required for a protective system entails special treatment. In view of the fact that we must limit the maximum, rather than the effective plate voltage, in order that the tubes may not be damaged during short circuits on the power system, saturated core principles are of no assistance.

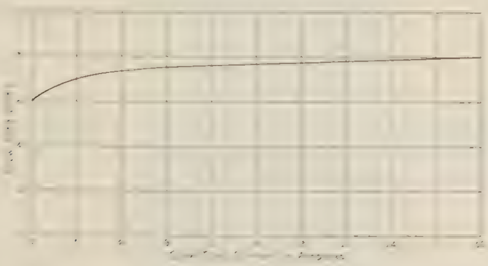

Fig. 6—Regulating Glow Tube Characteristic

This difficulty has been successfully overcome by the use of a special type of regulating glow tube, developed by the company's research laboratory. The characteristics of this tube are shown in Fig. 6. The tube passes no current until the voltage reaches 60 volts, when a visible glow appears. For any value of current up to 30 amperes, the voltage drop across the tube will not exceed about 80 volts. The appearance of this tube may be seen in Fig. 7.

Fig. 7—Plate Voltage Regulating Glow Tube

The glow tube is connected to a special secondary winding on the plate transformer, the action of the tube being illustrated in Fig. 8. As the primary current is raised, the voltage across the glow tube winding, and across all other windings on the transformer, will increase up to the point at which the tube commences to discharge. The values of the various plate voltages at this point and at higher values of excitation will be the glow tube voltage multiplied by the respective turn ratios. It will be noted that the tube controls the maximum voltage only and does not come into action until the instantaneous value reaches the glow voltage of the tube. The effect, therefore, on the wave form is to furnish a wave which is sinusoidal up to the point where the peak voltage is equal to the glow point of the tube. With higher values of excitation, there is no substantial increase in the maximum value of any of the secondary voltages, but the wave form becomes more and more rectangular. This characteristic is peculiarly favorable to this system of carrier current control in which the operation is independent of the wave form and of the amplitude, being solely determined by whether the wave is positive or negative.

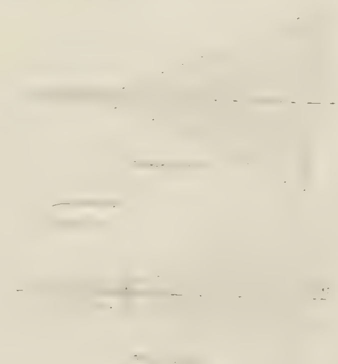

Fig. 8—Action of Glow Tube

Fig. 9 is an oscillograph record which shows the action of the glow tube. The primary current is varied over a wide range and the resulting effect on the plate voltage, which would be proportional to the current if no glow tube were present, can be seen very clearly.

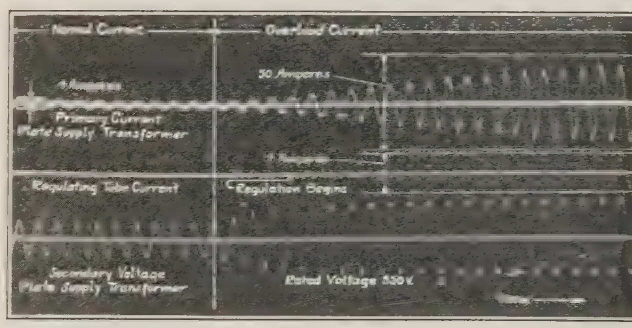

Fig. 9—Primary Current and Plate Voltage

Phase Relations

In the explanation of the operating principles of this system, it was assumed that when the line is sound, the two currents will be in phase and that when the line suffers a fault, the instantaneous currents will be of opposite polarity. In the development of this system, it

has been necessary to consider to what extent this is actually correct under service conditions.

In the case of a "through" short-circuit current, the currents at each end of the line are in actual fact identical, on lines of present length, except for the charging current of the line, which in most cases is small in comparison with the current at which the over-current relays would be expected to operate.

When the line itself suffers a fault, the two currents are not identical. They will usually be of different magnitude but will in general be very nearly 180 deg. apart in phase relations. There may be special cases. however, where the fault is fed from each end through circuits having different impedance power factors which may result in some slight departure from this phase relation, and this possibility has been studied. Fig. 10 is a polar curve which shows the affect on the current

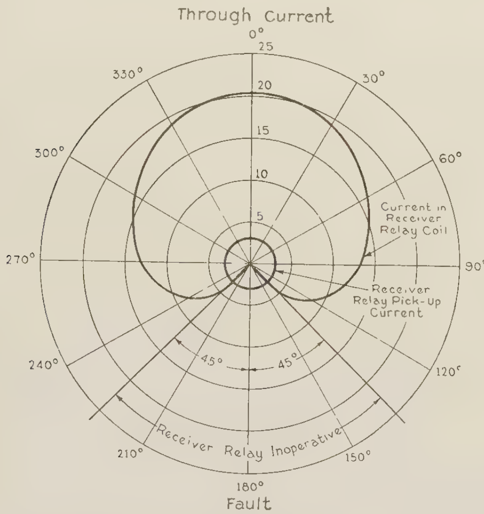

FIG. 10—EFFECT OF PHASE RELATION BETWEEN RECEIVER AND TRANSMITTER

in the receiver relay of variation in the phase relation between the primary currents exciting the transmitter and receiver. It is evident that in the case of a "through" short-circuit current, there is no risk of the receiver relay failing to pick up as the currents are identical. In the case of a short-circuit on the line, the relay should not pick up. It can be seen that there must be a difference of at least 45 deg. between the two currents before this can occur.

THREE-PHASE CIRCUIT

In order to apply this arrangement to the protection of a three-phase line, it is not necessary to use three carrier current equipments. All that is required is to furnish an arrangement of primary windings such that any possible fault condition will energize the plate transformer.

It will be necessary to bring the carrier apparatus into action on the occurrence of the following currents. We may refer to the three phase as A, B and C.

Three-phase fault on	A B C
Fault between lines	A B
Fault between lines	B C
Fault between lines	A C
Ground fault	A
Ground fault	B
Ground fault	C

The minimum number of exciting windings which will enable each of these conditions to furnish energy is three. By providing, therefore, three windings, of dissimilar numbers of turns, each of the above cases

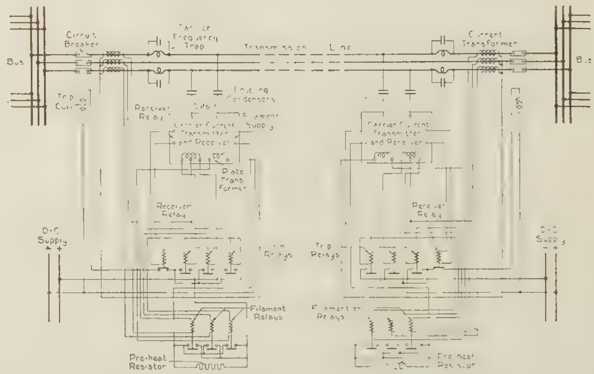

FIG. 11—THREE-PHASE DIAGRAM OF CONNECTIONS

will set up a resultant excitation of the transformer. The magnitude of this resultant will necessarily vary according to which of the above conditions holds. Since, due to the glow tube, the carrier-current system operates over an exceptional current range, this variation will be of no moment, provided that the minimum excitation,—that is, when the least effective combination of turns results,—is sufficient.

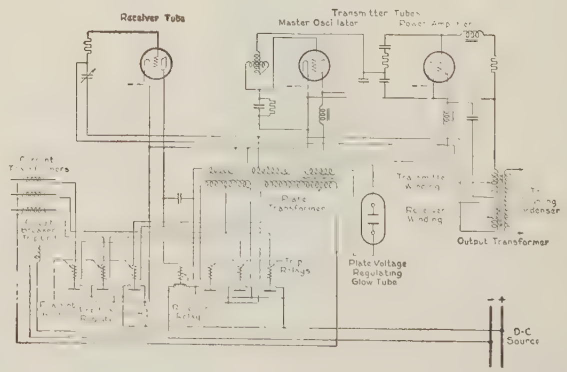

FIG. 12—CARRIER-CURRENT TRANSMITTER AND RECEIVER—THREE PHASE DIAGRAM

It is very often an advantage to be able to furnish more sensitive operation in the case of ground faults than where the trouble arises from a short between lines. Moreover, a ground fault, limited in magnitude, perhaps, by an earthing resistance or maybe by the high reactance or resistance of the abnormal return path, may not cause complete reversal of the current if an appreciable load is present.

Thus, it may be desirable to so arrange the means whereby the flow of current controls the carrier apparatus that a ground fault has a preponderating influence. We may do this by furnishing two windings of equal turns connected directly in the current transformer secondary circuit and one of an increased number of turns connected in the neutral circuit of the three-current transformers.

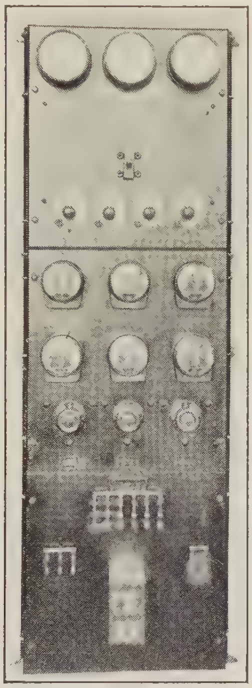

Fig. 13—Carrier-Current and Relay Panel

Three tripping relays and three filament relays are employed. In each case, one may conveniently be a ground relay which may be set to operate at a lower value of overload than the others. The general arrangement is shown in Fig. 11.

The complete connections for one end only are given in Fig. 12. It should be noted that the glow tube is energized by all kinds of faults. Therefore, while the primary current at which the glow tube comes into operation will vary according to the nature of the fault, the glow tube will always regulate all the plate and other voltages at the appropriate values corresponding to the turns on the several windings.

Conclusion

This system will furnish protection substantially equivalent to that which may be obtained with a pilot wire system, provided that the lowest phase-fault current at which it is desired to operate, is not less than the normal rated current of the line. In the case of ground faults, it is possible to obtain operation at lower values than full-load current.

In cases where it is required to take care of phase-fault, short-circuit currents, which are less than full load, it is desirable to install additional filament relays to avoid continuous operation of the tubes during normal load conditions.

The apparatus may be operated from bushing transformers as well as from standard types of current transformers.

Tests have been made on a 66-kv. line about 30 mi. in length. The apparatus was excited from standard bushing transformers. Actual short circuits, both between phases and to ground, were applied to the line itself or at neighboring locations. The system performed satisfactorily with fault currents which ranged from 200 to 1700 amperes.

Fig. 13 shows a front view of the equipment which was employed for these tests. The upper section of the panel carries all the carrier-current transmitter and receiver apparatus and instruments indicating the filament voltage of the tubes, the transmitter output current and the receiver relay current. The tuning adjustments can be seen in the photograph.

On the middle section are the filament relays, trip relays and filament rheostats.

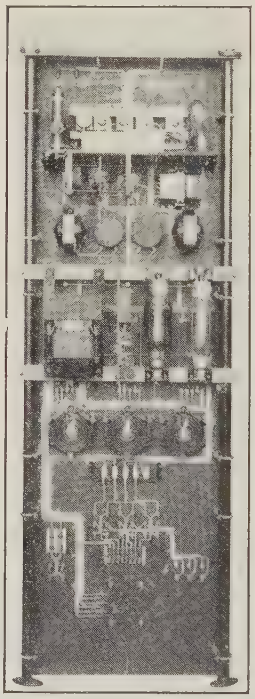

Fig. 14—Carrier-Current and Relay Panel, Rear View with Cover Removed

The receiver relay is mounted on the lower section which also carries the filament and test switches.

The carrier apparatus may be seen more clearly in the rear view Fig. 14. This section is normally protected by a cover. Back of the center section are mounted the plate transformer and the plate voltage regulating glow tubes of which two are shown in the illustration.

Production and Application of Light

Report of Committee on Production and Application of Light*

To the Board of Directors:

In accordance with requirements of the by-laws, there is submitted herewith a review of the development during the past year of the art of lighting with electricity. This review constitutes the annual report of your Committee on Production and Application of Light. It has been prepared through the cooperation of members of the Committee.

The personnel of this Committee has been chosen with a view to insuring comprehensive consideration of the subjects lying within the purview of the Committee. Its members concur in the view expressed by the Committee to Review Technical Activities in a report dated June 26th, 1924, to the effect that this Committee should function in an "initiatory and determinative" capacity in matters pertaining to the production of light and in a "joint or reportorial" capacity in matters pertaining to the application of light. Accordingly, the Committee endeavors to maintain close touch with developments in the production of light by electricity and looks to organizations more specifically concerned in the application of light for information as to developments therein.

Production of Light

No developments in the production of light from electricity which are new in principle or which constitute a radical improvement in the art have come to the Committee's attention during the past year. Progress in the development of illuminants described in earlier reports is reviewed briefly in the following paragraphs.

Incandescent Filament Lamps. In the following paragraphs there is presented a brief review of significant changes in manufacture and utilization of incandescent electric lamps.

The past year has witnessed the general introduction of incandescent lamps with bulbs frosted on the inner surface, announced in the report of this Committee last year. Eighty per cent of the demand for replaceable types is now being supplied by lamps of the new type.

Among tungsten filament incandescent lamps the gas-filled principle has been extended to lower wattages than heretofore employed in this type for general lighting purposes in this country, though not to such small wattages as those in which it has been sometimes employed in Europe. In the 50-watt 115-volt size the principle has been applied to what appears to be the minimum size for which its use is justifiable in the present state of the art.

Limited ability to withstand rough usage and vibration has always been a handicap of the tungsten filament lamp. Despite notable improvements by American lamp manufacturers, which have increased greatly the sturdiness of the filament, it remains true that after some hours of burning, the filament crystallizes and becomes less sturdy than the filament of a new lamp, and too fragile for some forms of service.

In an effort to meet requirements for rough service (for example, in garages, where lamps are used on portable cords), manufacturers have recently developed a "rough service" lamp. This lamp is available in the 50-watt, 115-volt range. It is of the vacuum type and has a bulb of the same size as the usual 25-watt lamp.

Where continuous, high-frequency vibration is encountered (as that due to high-speed machinery), the lamp manufacturers recommend, if small lamps must be used, the 50-watt coil filament vacuum lamp in the P-19 bulb. It is preferable, however, to use larger, more sturdy lamps, and if necessary, to employ vibration reducing devices.

Two lamps for decorative service have been made available during the year in new forms of flame-shaped bulbs. One is of 15 watts with a candelabra screw base. A similar lamp had previously been supplied in a bulb having spiral fluting. The other is a 25-watt lamp with a medium screw base. These lamps are regularly supplied with a flame tint coating to add to the effect suggested by their flame shape.

According to a recent report issued by the Lamp Committee of the National Electric Light Association, carbon lamps are being used to a surprisingly large extent in ordinary lighting service. Because of their relatively low efficiency, the cost of producing light with these lamps usually is greatly in excess of that applying in the case of tungsten filament lamps.

The trend of operating practise appears to favor 115 and 120 volts. The demand for 110-volt lamps is steadily decreasing and is now only 12 per cent of the total in the 100-130-volt range; 115 volts accounts for 48 per cent and 120 volts for 35 per cent, leaving only 5 per cent for all other voltages in this range. The total number of lamps supplied from 200 to 260 volts is now but 3 per cent of the number supplied in the 115-volt range and this percentage is gradually diminishing. The concentration of lamp demand upon the fewest practicable number of voltages is desirable as a means of eliminating needless and expensive complications in manufacture and distribution.

The 23- and 36-watt lamps for street railway headlight service are now made in the "A" shape bulb of clear glass. The change from the round bulb

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P. S. Millar, Chairman

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J. R. Cravath,	H. H. Higbie,	B. E. Shackelford,
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	George S. Merrill,	

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927.

(G-18½) in which they were formerly supplied, enables one standard light center length of 2 3/16 inches to replace 2 1/16 inches, 2 3/16 inches and 2¼ inches light center lengths in the old bulbs. This can be done because the shape of the A bulb permits a wider range of adjustment of lamp position in the headlight.

A special lamp has been developed for use in traffic signals. It is a 60-watt gas-filled tungsten filament lamp in a clear bulb of the shape and size used for the regular 40-watt lamp in the inside-frosted line. The filament is semi-concentrated to permit of more accurate light control by the signal lenses. The lamp has a light center length of 2 7/16 inches. It is designed for burning in either a horizontal or base down position.

To premote simplification in the line of lamps for series burning, it has been recommended that street lighting circuits now operating at 4, 5.5 and 7.5 amperes be changed over to 6.6 amperes, for which there is by far the greatest demand. The progress of standardization in this respect is slow.

There is still a demand for series burning lamps of 600 and 800 lumens (approximately 43 and 55 watts respectively) which, it is generally believed, could be replaced advantageously with lamps of at least 1000 lumens (approximately 65 watts).

Series Lamps Unsatisfactory on Multiple Circuits. Some use has been made of series lamps operated with auto transformers from multiple circuits. Investigation of this form of operation has shown that multiple lamps operated on multiple circuits are more economical and give more satisfactory performance than any of the series lamp auto transformer combinations. The series lamp is designed to burn at a constant current which means that the filament cross sectional area is very accurately determined while variations in manufacture are noted by changes in filament length. This manufacturing variation is particularly noticeable when a series lamp is burned on a constant voltage circuit. Furthermore, in the larger size series lamps, a large amount of filament material during the normal life of the lamp is evaporated and deposited on the bulb. This blackening causes a decrease in lamp candle power. When the series lamp is operated on a constant current circuit the decrease in filament area results in an increase of brightness which partially offsets the blackening of the bulb. A lamp burned at constant voltage however, suffers because of diminution of current as the lamp ages due to increased filament resistance. It is seen, therefore, that all the factors present in both multiple and series lamps which make for decrease in lamp output are combined when a series lamp is operated on a constant voltage circuit.

The lamp manufacturers recommend that multiple lamps be burned on multiple circuits and that series lamps be burned only on series circuits.

Luminous Arc Lamps. It is understood that there have been no material changes in the design of construction of the luminous arc lamp during the past year. The modern lamp, with its shorter casings and larger globes, as constructed for service in Washington and elsewhere, represents the latest development in this type of lamp which, as shown elsewhere, is employed rather extensively in street lighting service.

Ultra-Violet Radiation. Efficient production of ultraviolet radiation is accomplished by electric discharge through vapors, usually of a metallic nature. The conditions of use impose the further limitation that the source, particularly one of the arc type, be completely enclosed to prevent the egress of undesirable vapors in therapeutic work, or the ingress of inflammable vapors in chemical work. The mercury arc in quartz, being inherently an enclosed arc, is uniquely adapted to use as a source of ultra-violet radiation. Units of 450 and 900 watts capacity for operation on 110 and 220 volts respectively have met with increasing use during the past five years. The former are used largely in therapeutic work for the direct irradiation of patients in the treatment of rickets, bone tuberculosis, skin diseases, superficial infections, etc., while the latter are used for water sterilization, the testing of materials, irradiation of foodstuffs to produce antirachitic properties, the treating of leather, varnishes, etc.

The use of rare gases as an aid in the starting of discharge has recently permitted the design of a practical induction lamp having unique properties when made of quartz. It permits greater control of the relative ultra-violet energy distribution than before was possible and it is especially well adapted to the solution of many of the mechanical problems limiting the usefulness in photochemical processes of the older mercury arcs.

It is said to be possible to duplicate economically by means of these artificial ultra-violet sources practically any photochemical effects now secured through exposures to direct sunlight. This is important for sunlight, though inexpensive, is offset by the fact that it is of value only during the middle five hours of the day, if available at all.

As an example of a highly developed ultra-violet application, mention may be made of a recently designed apparatus in which, by means of a quartz mercury arc and filters, tests may be made of the light fastness of dyed textiles, inked papers or painted woods in a much shorter time than ever has been possible by sunlight and with a quality of fading action directly comparable with that of sunlight.

Application of Light

In contrast with the relatively meager developments in the production of light, the past year witnessed a wealth of development in the application of light. Artificial light is now available at such a low cost that improvement in its utilization can be undertaken with greater freedom. In consequence the lighting art is advancing rapidly.

Residence Lighting Equipment. The past year has seen an expanding interest on the part of central station

companies in residence lighting equipment. Several companies have conducted re-fixturing campaigns with marked success and many are planning such activities for the current year.

Interest in this project is evidenced by the preparation, beginning in the autumn of 1925, of tentative specifications for residence luminaires, prepared under the supervision of a committee of the Association of Edison Illuminating Companies, with which the Illuminating Engineering Society has cooperated. These specifications promote consideration of a luminaire from three principal standpoints:

1. Illuminating qualities
2. Mechanical and electrical construction
3. Aesthetic values

The application of these specifications results in a final figure of percentage which represents the over-all quality rating for each luminaire considered. Part of the determination of necessity must be arrived at by personal judgment and part by laboratory measurements. Very consistent results have been obtained by using averages of the personal judgments of several competent persons. An interesting by-product of this activity is the production of a practicable glare-gaging device, in the form used in the measurement of glare in residence luminaires.

The Home Lighting Committee of the National Electric Light Association has already prepared outlines of typical plans for such re-fixturing campaigns. Other information and material is being prepared and will be disseminated by that Committee throughout the year. The month of October has been chosen as the period of specialized activity in promoting improved residence lighting.

There is a noticeable trend in manufacturers' lines toward luminaires embodying provisions for the shading of lamps, although the development is far too slow to be considered as satisfactory. Several inexpensive devices are on the market to enable the use of shades on modern types of lamps.

Street Lighting. The attitude of the electrical industry toward street lighting seems to be undergoing a wholesome alteration. Street lighting is coming to be regarded as a phase of utility operation which is capable of becoming remunerative both to the community and to the utility. Accordingly, both the engineering and commercial aspects of street lighting are being given more intensive and forward-looking consideration than in the past. It is coming to be recognized that through comprehensive planning, coupled with general plans for city improvements and growth, economies may be had through standardization, reduced obsolescence, efficient energy distribution and control.

It is generally recognized that street lighting deserves the accurate methods of the engineer since nationally we are confronted with the need for many extensive improvements. There is dawning a new era in street lighting, trailing the new era in vehicular traffic. Street lighting systems for the main streets of large cities, and some already in use, have been designed to deliver 50,000 to 150,000 lumens (2- to 6-kw. demand) per standard instead of 10,000 to 15,000 lumens (0.5- to 0.75-kw. demand) which was considered adequate in the past.

Progress has been made in the manufacture of equipment for remote control over existing commercial networks to widely scattered relays actuating switches to supply the street lights from existing distribution systems. Several new remote control switches, both solenoid and motor operated, have been developed to be controlled from a pilot wire.

These new equipments are suitable to supply the power for either series or multiple lamps and may be selectively arranged to disconnect alternate units during the late hours of the night when there is little traffic. These various control equipments are receiving more attention with the trend toward increased load density.

There has been considerable activity in the further development of enclosing glassware for street lamps. The tendency seems to be in the direction of a compromise between directional control and diffusion, the one intended to place the light where it is wanted, and the other to avoid excessive glare.

In overhead lighting equipments the trend is definitely toward the use of dust-proof units, to obtain a higher average efficiency between cleaning periods by avoiding the absorption of light otherwise due to the collection of dirt on the lamp bulb, and on enclosing accessories.

The Illuminating Engineering Society's Committee on Street Lighting is making progress in developing a method of appraising the qualities of street lighting to determine the relative illuminating merits of various street lighting installations.

The Street and Highway Lighting Committee, National Electric Light Association, has outlined a three-year program to cover thoroughly the sales and financing aspects of street lighting systems. It purposes issuing a manual on street lighting.

The lighting of interurban highways is slowly progressing with promise of greatly accelerated growth in the near future. Rural electrification is an interlinking factor, and nation-wide legislation providing enabling acts is the primary desideratum. There are many indications that as legal obstructions are removed, large growth in highway lighting will follow. The problem in its present status is one of legislation rather than of engineering. However, more engineering analysis and evaluation of the social economic aspects of highway lighting will hasten the required legislation.

Table I presents a partial list of intensive street lighting systems in the United States as of March 1st, 1927. Additional intensive installations are being made or are planned in several other cities. From this list it is evident that existing high intensity installations

are divided between luminous arc and tungsten lamps, although present indications point to a trend toward tungsten installations in the immediate future.

PARTIAL LIST OF INTENSIVE STREET LIGHTING SYSTEMS. AS OF MARCH, 1927

	Lumens per linear foot of street*		
Chicago, State Street	2000	2-lamp	tungsten
Seattle, Metropolitan Avenue	1050	2 "	"
Jersey City, N. J.—Journal Square Plaza	857	1 "	"
Salt Lake City, Business Section	822	3 "	arc
Niagara Falls, Falls Street	761	2 "	"
San Francisco, Market Street	750	3 "	"
Schenectady, Erie Boulevard	700	2 "	"
Portland, Oregon—Business District	600	2 "	tungsten
Columbus, Ohio—Business District	600	2 "	"
Schenectady, State Street	585	2 "	arc
Los Angeles—Several streets	375 to 510	2 "	tungsten
Indianapolis, Business Section	520	2 "	"
Los Angeles, Broadway	510	2 "	arc
San Francisco, Triangle District	500	2 "	"
El Paso, Business Section	500	2 "	"
Cleveland, Superior Avenue	500	1 "	tungsten
Rochester, N. Y.—East Main and East Ave.	472	2 "	arc
Lynn, Mass.—Central Avenue	450	2 "	"
Augusta, Ga.—Broad Street	450	2 "	tungsten
Davenport, Iowa—Business Section	450	2 "	"
Syracuse, Business Section	425	2 "	arc
Boston—Several business streets	400	1 "	"
Boston—Massachusetts Avenue	400	1 "	tungsten
Lansing, Michigan—Business Section	400	2 "	"
Lawrence, Mass., Essex Street	400	2 "	"
Chicago, South State Street	400	1 "	"
Gary, Indiana—Business District	381	2 "	"
Lynn, Mass.—Business District	351	1 "	arc
Racine, Wisconsin—Business District	350	1 "	tungsten
Chattanooga, Tenn.—Business District	340	1 "	"
Cleveland—Business District	333	1 "	"
Worcester, Mass.	325	1 "	arc
Utica—Business District	304	1 "	"
Saratoga, Broadway	300	2 "	tungsten
Lowell, Mass.	300	1 "	arc
Nashua, N. H.—Business Section	300	1 "	"
Providence, R. I.—Business Section	300	1 "	"

*As an index of grade of lighting "lumens per linear foot" is evidently inexact. No better basis of terse statement is, however, available for these installations.

Signal Lights for Traffic Control. The need of standardization of electric traffic signals is apparent. In some cities one may make a right or left turn on a red signal while in others such a movement is prohibited. There seems to be a divergence of opinion as to whether there should be three colors or two. A committee appointed by the governor of an eastern state has recently gone on record as approving a two-color system, while a similar committee in a neighboring state has also gone definitely on record as favoring a three-color system. Tourists traversing these two states are likely to encounter trouble.

There also seems to be a wide difference of opinion as to the proper location of signals. Some city officials prefer the pedestal type mounted in the roadway; others prefer the bracket type of suspension from messenger wire across the street. It is not unusual to hear of controversies between officials of the State Highway Department and of municipalities as to the type of signal. Most of the State Highway Departments will not permit the use of pedestal type signals on the roadway owing to the fact that if they fail to light they become a hazard.

The lack of standardization in the use of the colored lights in connection with the control of traffic has made it difficult for the police to enforce the regulations. It is needless to dwell further upon the chaotic conditions which exist at the present time. The traffic problem requires the cooperation of the architect, civil engineer, police officials, electrical engineer, illuminating engineer, transportation engineer, etc., in order that all the various phases of the problem may receive due consideration. All of these are concerning themselves with it, but often independently and without coordination.

In a recent number of the *Architectural Forum* there is an article by a nationally known architect which deals with the relation of the height of buildings and the density of pedestrian traffic upon the streets.

Out of this maelstrom of independent activity comes the announcement of the organization of a committee of the American Engineering Council, under the chairmanship of Dean Dexter S. Kimball, of Cornell University, which shall study the problem and prepare a standard code, so that when the automobilists from New York are driving in San Francisco, or vice versa, the signals will carry the same message. Such standardization now exists in the railroad industry where red to the railroad man means only one thing—danger. Yet the general public has been educated to regard the use of red light in a building as a safety exit in case of fire, or, on a street, a safety aisle. In navigation the use of red for port and green for starboard is standard the world over. Possibly after the standardized code for the control of traffic is available, action can be taken to replace the red lights in the interior of buildings as an indication of safe exits in case of fire.

Automobile Headlighting. The art of automobile headlighting is receiving a great deal more attention than many people, perhaps, know. While it cannot be said that any great developments have been recently consummated, it is still a fact that efforts by many agencies, along different lines, but all directed toward the same object, have considerably advanced the general knowledge of the subject and have brought an ultimate satisfactory situation just so much closer. Among such activities now in progress, are: recognition of the Uniform Vehicle Code, enforcement of headlight laws, activities productive of a better understanding of the nature and prevention of glare, the relation of automobile headlighting to street lighting, mechanical requirements for headlights, and recognition of the shortcomings of present equipment.

The most notable development in automobile lighting practise during the past year has been the very general adoption by manufacturers of the better grades of cars, of a changeable beam headlighting system. This has been approved by all the states as legal. A brief review of the history of this development may not be out of place here.

A number of years ago, the Illuminating Engineering Society and the Society of Automotive Engineers,

working together, endeavored to improve the unsatisfactory condition of automobile headlighting by adopting a set of minimum and maximum limits covering a light distribution that would yield a maximum of good driving light and a minimum of objectionable glare. These limits were based on permanent and fixed adjustment and pointing of the headlights. In the nature of things, these limits were a compromise, but were so well worked out as to produce a marked improvement in road driving conditions after dark.

Since these limits were adopted, however, there has been a considerable change in many of the elements of the problem. The average height of the eyes of drivers above the road surface is considerably less than it was five years ago, due to the constant lowering of cars. Vehicle springs are now being made softer than they used to be. Cars therefore pitch through greater angles due to road inequalities. Furthermore, because the passenger load comes very largely on the rear springs, there is a big change in car angle under varying conditions of load. Having these changed conditions in mind, committees of the Society of Automotive Engineers and of the Illuminating Engineering Society jointly undertook to devise specifications covering the use of an alternative distribution of the headlight beam for use in passing another car. The driver is then expected to change from one type of distribution to the other as conditions demand. Experience has shown that drivers can be trusted to do this if they are provided with a reasonably good passing light.

By the use of the alternative system of distribution of the beam, two things are accomplished: first, a great amelioration of the glare d'fficulty is obtained by the use of the changed beam, and second, since the beam can be removed from other drivers' eyes, the adjustment of the headlamps may be such that the top of the beam is higher than with the fixed beam equipment, thus providing a better driving light where the absence of oncoming cars renders it practicable to keep the beam in its normal position.

At the present time, a joint committee, composed of members of the two societies, is conducting research to determine the proper limits to govern the new types of light distribution. Without waiting for the final results of this committee's work, many motor car companies are adopting systems in which the regular driving beam is lowered through an angle of two or three degrees in passing another car. A number of simple and economical ways are now available for accomplishing this result and the public approval of the change has been very marked

The old system of reducing the candle power by dimming is condemned by everyone and it is hoped that it will become obsolete in the near future.

Lighting of Exteriors. The advantages of flood lighting have been amply demonstrated, not only by the number of large installations during the past year, but by the diversified character of the installations. Illumination intensities have in general been higher, and larger numbers of projectors have been used on individual installations than have ever been used before.

Two state capitols, those of New Jersey and Texas, were added to the list of half a dozen or more that have been flood-lighted previously. Two large office buildings in Detroit were lighted; in one case over three hundred and the other over one hundred projectors were used. In Brooklyn over one hundred projectors were used on an office building, and in New York nearly five hundred projectors are employed to light the upper portion of a new theater. Kansas City has lighted its huge war memorial by means of searchlights; steam emerging from the top is illuminated by colored light from projectors concealed in the top.

Great interest is developing in lighting recreational areas. In order that children may be kept from the streets, school and public playgrounds have been lighted. Colleges in increasing numbers are lighting their stadiums for night football. Considerable impetus was given this movement by the success of the lighting of the stadium at the Philadelphia Sesqui-Centennial grounds.

Electric Signs for Daylight Use. Electric lighting display, having been highly developed in this country for night use, is being extended into the daylight hours.

Tubes of neon and other gases or vapors offering striking color contrast with daylight are entering into service in some sections of the country quite extensively. This follows a like development in Europe.

The diameter of the neon tubes which are ordinarily employed for signs varies from 7 to 32 millimeters (usually 11 to 15 millimeters). The characteristic orange-red color of neon predominates in displays erected to date but other colors are to be seen. These are derived from the admixture of helium, argon, etc. The characteristic radiation of mercury vapor is likewise to be seen in some signs.

The tubes vary in length from 10 to 40 feet. Starting voltages are approximately 200 volts per foot of the tube; alternating current 25 to 60 cycles is employed, rotary converters being used where the supply is direct current.

For typical tubes of 20-foot length and 15-millimeter diameter, the manufacturers state that the consumption is about 200 watts. This increases rapidly if the diameter of the tube is increased. The power factor of such a sign is stated to be approximately 50 per cent.

The usual filament-lamp electric signs are being adapted in some cases to daytime use. For this purpose an aтea of brightness is built up optically so that the entire surface of a letter is given the brightness of the filament itself when viewed from certain directions.

In obtaining a large area brightness, the light has been concentrated into a relatively narrow angle; hence, within this angle only is its effectiveness at a maximum. Such a sign is of greatest value when the traffic is massed within a relatively narrow viewing angle, and where

people approach the sign nearly "head on" for a considerable distance. There are many such locations—atop the marquise projecting over the sidewalk; at a dead-end street; on a highway curve;—where the new type of sign may be effective.

Illuminated Bulletin Boards. The use of illuminated poster and bulletin boards is rapidly increasing and it is noted that more consideration is being given architectural features as well as the use of novel lighting, and mechanical effects.

The appearance of animation or action is sometimes accomplished through color by the absorption method. The advertisement is painted on the bulletin board with carefully selected oil colors. There are two lighting equipments, one for example, for red lighting and the other for blue-green lighting. Supply circuits are controlled by a two-circuit flasher so that by the alternate flashing of the red and blue-green lights, the fading out of certain words or images on the bulletin is accomplished. For example, the red light will apparently "absorb" the red painted images or words on the sign leaving visible only the darker colors which do not contain red. Equivalent effects are had with the blue-green.

A rather interesting mechanical bulletin board has made its appearance in the Middle West. The face of this board consists of a series of equilateral triangular members each of which operates on an axis so that the entire face of the sign revolves simultaneously. In this manner three separate advertisements can be painted on the respective faces of the triangles. An electric motor operates the mechanism so that the sign may be changed four times a minute. These displays are illuminated for night operation.

A rather effective plan has been worked out whereby the use of a modern show-window is combined with a billboard. The show-window is built flush with the face of the bulletin. The bulletin bears the usual advertising, while behind the plate glass of the show-window is arranged a display of merchandise. The face of the bulletin is lighted by means of angle reflectors in the usual method and the interior of the show-window is illuminated with show-window reflectors.

It is interesting to note that the electrical advertising industry has taken action to improve the appearance of bulletin boards and also to restrain members of their industry from installing posters and bulletin boards in places where they impair the beauty of the scenery. The unrestrained activity on the part of various poster advertising companies in locating their stands in places where they detract from the natural beauty of the landscape has caused very unfavorable public comment and it is logical that the industry should take action to remove the cause of the criticism.

Lighting for Aviation. The rapid advance of aviation, especially in the United States Air Mail Service, has given rise to demand for lighted air-ways. It is reported that 3700 miles of transcontinental route are now lighted and appropriations have been passed for lighting the following routes for 1927:

New York to Boston
St. Louis to Chicago
Dallas to Chicago
Salt Lake City to Los Angeles
Pasco to Elko
Chicago to Twin Cities
Cheyenne to Pueblo

Under the auspices of the Department of Commerce there has been developed a lighting system, employing usually 24-inch revolving beacons, equipped with 900 or 1000-watt tungsten lamps located at average intervals of ten miles along the air routes. Intermediate landing fields are located every 25 miles along the routes, each equipped with a beacon and 20 boundary lights. A green approach light and red lights on top of obstructions near the fields are used.

A typical airport has approximately 30 kw. of lighting load, involving from $5000 to $12,000 worth of lighting equipment. It comprehends:

1. Revolving beacon to guide the aviator to the airport.
2. Boundary lights (60-c. p. series) all around the field to show the limitation of the boundary area.
3. Red lamps on all obstructions near the field, such as radio towers, telegraph poles, etc.
4. An illuminated wind indicator to show the strength and direction of the wind.
5. A ceiling light (1000-watt, 18-inch searchlight to show the height of the bottom of the clouds.
6. Flood lights on the roofs and sides of the hangars (200-watt lamps).
7. A high-intensity arc searchlight, or a couple of 10-kw. tungsten lamps to floodlight the landing field itself.

There are already nineteen lighted fields in the United States and forty others from which regular flying is being done on such schedules that lighting is required. Many cities are alive to the coming air commerce, and are appropriating funds to prepare lighted ports. It is a movement which is spreading very fast. Estimates indicate that by the end of next year there will be 2000 lighted fields in the country.

In 1926 the Post Office Department used on their fields in the Air Mail Service, 3710, 900- and 1000-watt lamps; 1920 200-watt lamps and 1440 600-lumen series lamps. The 1927 plans are for over three times as much air mail service as in 1926, with a corresponding increase in lighting.

Subterranean Lighting. The new vehicular tunnel from New York to Jersey City offers the outstanding installation of this class of electric lighting. It will probably be the most heavily traveled long tunnel in the world.

Although the main travel will be in one direction in each of the two tubes, the use of unidirectional lighting was impracticable because of the possibility of only one

tube being used for travel in both directions when repairs are being made. The lighting is accomplished by incandescent lamps behind windows set at the joints between the side walls and ceiling, and arranged so that the units on one side illuminate the opposite half of the tunnel, and avoid glare in the eyes of drivers. About two foot-candles are provided, with an overlapping distribution to minimize shadows from high vehicles.

At each end additional light is provided for daytime use, to lessen the contrast with daylight.

Railway Lighting. Developments in lighting in the steam railroad field during the past year or so have largely kept pace with the general development in other fields of lighting. As a whole, railroads are appreciating the benefits of higher intensities of illumination, particularly in shops and offices where artificial illumination may be required a large percentage of the time, with the consequence that the average levels of illumination intensities for interior lighting throughout the railroad field are being considerably raised.

Considerable attention is being given to providing better illumination in passenger carrying cars. In the matter of intensities the best practise of today represents from 75 to 100 per cent higher average illumination intensities than the practises of eight or ten years ago. This has been made possible by the improvements in the efficiencies of train lighting lamps and the successful development of lamps of higher wattages, also the development of economical car lighting axle generator equipment and batteries of larger capacity.

The past year has seen very rapid growth in the general interest in the subject of flood lighting as applied to railroad yards, as well as the application of this system at a rapidly increasing rate. The proper and economical lighting of large railroad yards presents many problems, in which connection, until recently there has been available but comparatively little engineering data that would aid in laying out such lighting systems. There is also still considerable difference of opinion among railway engineers as to the system of flood lighting that will produce the most effective results. This subject is being actively studied by the Committee on Illumination of the Association of Railway Electrical Engineers and it is expected that by another year illuminating engineering practise in the application of flood lighting in this field will gradually crystallize along definite lines of procedure.

In view of the number of lighting problems that are more or less peculiar to the lighting field the Association of Railway Electrical Engineers has also prepared, with the assistance of the illuminating engineering staffs of the incandescent lamp manufacturers a "Manual of Lighting Practises for Railroads" which serves as a general code of lighting practise as applying to this field.

Illumination of Outdoor Substations. The illumination of outdoor substations is primarily intended to facilitate operation, but it has been found, in many cases, to have an advertising value as well. One installation recently described in the technical press emphasized the advertising value by employing a hot galvanized finish on all structural steel and two coats of aluminum paint on transformer cases, switch housings and other exposed metal surfaces.

Lighted Ornaments. Artificial light has been employed thus far primarily for utilitarian purposes. Only occasionally, and to a very slight extent, has it been employed in residences for the illumination of ornaments. Evidently the potentialities of such employment of artificial light are very great. There are some indications that these potentialities are beginning to be realized, and in the not very distant future the employment of lighted objects of decoration solely for the purpose of ornament may assume considerable proportions.

Related Topics

Photometry. Progress in photometry during the past year has been principally in the application and use of the photoelectric cell in conjunction with suitable light filters. At the present time photoelectric photometers are largely used for routine measurements of incandescent lamps; this includes street series lamps, miniature lamps, colored bulb lamps, etc. The photoelectric cell equipment has also been adapted to distribution photometers, the spectro-photometer and color temperature determinations.

The extreme sensitivity of the photoelectric cell equipment has permitted the establishment of light values to a much higher degree of accuracy than obtains with visual methods.

Effect of Illumination on Industrial Production. The Committee on Industrial Lighting of the Division of Engineering Research of the National Research Council has completed a three year study of the effect of illumination upon industrial conditions. A report covering this investigation will be published in the near future and will contain many points of interest to illuminating engineers and factory managers alike.

Lighting Service Manual. A manual for Lighting Service Departments, under preparation by a committee of the National Electric Light Association, is approaching completion. Part 1, which deals with the lighting field, organization activities, etc., has been finished. It will provide an excellent guide for central station lighting activities.

Schools of Lighting. Evidence of the increasing interest in illumination is shown by the demand for local lighting schools. These have become more numerous during the past year. As a rule they are promoted by individual central stations for the benefit of their employees engaged in lighting. In several instances they have included local electrical contractors and dealers and when this has been the case, the schools have been held under the auspices of a local electrical league or some similar body. The instruction in

these schools has been conducted mainly by the incandescent lamp manufacturers.

Illumination Items in the Journal. In view of the fact that lighting programs are included in Institute meetings only occasionally, this Committee has found it expedient to endeavor to keep Institute members advised of lighting developments through the medium of brief articles which appeared from time to time in the columns of the JOURNAL. List of titles of articles which have appeared during the past year is as follows:

A Daylight Electric Sign.

Lighting Totaling 25,000,000 Candle Power Burned Nightly in Broadway Signs.

Europe Organizes Its Lighting Activities.

Inside Frosted Lamps.

Trend of Electric Lighting.

Must the Traveler Read Slowly?

Practical Color Photometry.

Industrial Lighting Activity of N. E. L. A.

Meet the Well Lighted Car.

European Lighting Progress Discussed at Rome.

Illuminating Engineering in Germany.

Home Lighting Contest in France.

British Lighting Contest begins with a Burst of Enthusiasm.

A Recent Lighting Demonstration in Holland.

Incandescent Lamp Ratings in France.

Artificial Lighting in Foundries.

British Investigate Light and Industrial Efficiency.

Carbon Lamps.

CONCLUSION

The Committee on Production and Application of Light, notes with satisfaction advances which are being made in the application of electricity in the field of illumination, and is gratified to observe a tendency of the related industries to organize for more effective achievement along these lines. The potentialities in this field the Committee believes to be great, both in prospective engineering achievement and in benefit for the public.

P. S. MILLAR, *Chairman.*

Electrophysics

Annual Report of the Electrophysics Committee*

To the Board of Directors:

The general views of the chairman of the committee will be found in the editorial entitled *Relationship between Physics and Electrical Engineering,* in the JOURNAL for February, 1927. This editorial may be considered as part of this report. During the year, some of the members of the committee volunteered to watch new developments in the following topics: Ferro-magnetism, theory of mapping of fields, short-time phenomena, high-voltage research, insulation and dielectrics (solid, liquid, and gaseous), arcs and discharges, short-wave propagation, atomic physics, spectroscopy, quantum theory, and surges. This list will give an idea of the scope of interest in electrophysics. Several manuscripts submitted to the Institute were read and passed upon by the committee.

The committee has felt that a constant influx of new ideas from the field of pure physics to Institute membership should be carefully maintained, in order that the profession might promptly take advantage of new discoveries, methods of measurement, and theories. As a partial realization of this endeavor, the committee desires to report as follows:

1. It has obtained permission from your Board to invite two members of the American Physical Society to sit with the committee. It is hoped that this arrangement will actually go into effect after August first.

2. It has obtained permission from the editor of *Physical Review* to publish in our JOURNAL abridgments of any papers appearing in the *Review,* with the usual credit. This will make it possible to note important articles immediately after their publication.

3. It has arranged with Professor K. T. Compton of Princeton University to write a paper on *The Nature of the Electric Arc* for presentation at this convention. It is hoped that another prominent physicist may be secured to address our next Winter Convention and that such addresses may become a regular practise in the future, at least at Winter Conventions.

PAPERS PRESENTED

The following papers and articles, which appeared in the JOURNAL during the period covered by this report, will give an idea of the range of topics in electrophysics covered. While not all of these papers were presented under the auspices of the Electrophysics Committee, they all lie within the scope of the committee's interests. The pages refer to the JOURNAL.

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Temperature of a Contact and Related Current-Interruption Problems, J. Slepian, October, p. 930.

Measurement of Transients by the Lichtenberg Figures, K. B. McEachron, October, p. 934.

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*Committee on Electrophysics:

V. Karapetoff, Chairman
Carl Kinsley, Secretary

Oliver E. Buckley,	W. B. Kouwenhoven,	Chester W. Rice,
V. Bush,	K. B. McEachron,	J. Slepian,
J. F. H. Douglas,	R. A. Millikan,	Harold B. Smith,
Charles Fortescue,	J. H. Morecroft,	Irving B. Smith,
Carl Kinsley		J. B. Whitehead.

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927.

The Space Charge That Surrounds a Conductor in Corona at 60 Cycles, J. S. Carroll and H. J. Ryan, November, p. 1136.

Coolidge's Cathode Ray Tube, November, p. 1143.

Vacuum Switching Experiments, R. W. Sorensen and H. E. Mendenhall, December, p. 1203.

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Frequency Measurements with Cathode Ray Oscillograph, F. J. Rasmussen, January, p. 3.

Maxwell's Theory of Layer Dielectrics, F. D. Murnaghan, February, p. 132.

A New Electronic Rectifier, L. O. Grondahl and E. H. Geigher, March, p. 215.

Space Charge and Current in Alternating Corona, C. H. Willis, March, p. 272.

Oil Breakdown at Large Spacings, D. F. Miner, April, p. 336.

Graphical Determination of Magnetic Fields, A. R. Stevenson, Jr., and R. H. Park, Winter Convention. E. E. Johnson and C. H. Green, June, p. 583.

Electrical Discharges in Gases

Disruptive Discharges. Using a development of Townsend's theory of ionization by collision, it has been proved possible to design electrode shapes of high-voltage spark-gaps so as to obtain minimum electrode size. "No time-lag" electrodes so designed are much smaller than corresponding "no time-lag" spheres, (Rogowski and Rengier, *Archiv. f. Elektrotech.*). A study of time lag of spark-over of gaps has shown that in many cases the duration of the lag is a matter of chance and must be dealt with statistically, (McEachron, A. I. E. E. Journal; Braunbek, *Zeitsch. f. Physik*). The influence of the state of electrode surfaces on time lag has been confirmed, (Burawoy, *Archiv. f. Elektrotech.*). The Townsend theory of ionization by collision seems to be inadequate for explaining the shortness of the time lag, (Rogowski, *Archiv. f. Elektrotech.*). Progress has been made in the theory of lightning, (Simpson, *Proc. Roy. Soc.*; Dorsey, *Frank. Inst. Jl.*); experimental work has been done aiming to discover the manner of striking of lightning, (Peek, *Frank. Inst. Jl.*).

Corona. Progress is being made toward a rational theory of corona, and the influence of space charge in the discharge is being taken into account, (Carrol and Ryan, Jl., A. I. E. E.).

Arcs. An improved equation for the volt—ampere characteristic of an arc, with one constant of the equation directly related to the boiling point of the anode, has been developed, (Nottingham, *Phys. Rev.*). Experimental and theoretical evidence has been produced for the existence of cold cathode arcs, (Newman, *Phil. Mag.;* Slepian, *Phys. Rev., Frank. Inst. Jl.*).

Miscellaneous. Important formulas have been theoretically derived and experimentally confirmed for the properties of electrodes immersed in gaseous electrical discharges, (Langmuir and Mott-Smith, *Phys. Rev.*). Cathode rays due to very high voltages have been brought outside the vacuum tube, and have produced strange phenomena, (Coolidge, *Frank. Inst. Jl.*).

Short-Time Phenomena

Much progress has been made in developing instruments for the determination of the characteristics of short-time electrical phenomena. Through the use of the modern cathode ray oscillograph of the Dufour type, it is now possible to determine the relationship between time, voltage, and current for any device operating under transient conditions, such as a lightning arrester.

Heretofore, it has only been possible to calculate wave fronts, and such calculations were of course limited to the assumptions made and frequently gave results considerably in error because of the presence of unsuspected oscillations. The cathode ray oscillograph has been used successfully for transients whose crest voltage was attained in one ten-millionth of a sec.

The propagation of waves over circuits and effects of reflection points, the breakdown of insulation, and other similar problems, are being actively studied with the help of this oscillograph. It is also being used to study the effects of lightning on transmission circuits, and gives for the first time an opportunity for the determination of the character and form of transients due to lightning.

For the purpose of making field studies of transients and transmission lines, surge recorders based on Lichtenberg figures have become of very great importance. The magnitude, polarity, and frequency of occurence of disturbances have been determined for many systems. These data have added greatly to our knowledge of phenomena for which there were only few quantitative data in the past. The measurements cover a very wide range of voltage, having been made on practically all ratings, from telephone circuits to 220-kv. transmission systems.

The surge recorder is also very useful in the laboratory as a device for measuring the potential of transients, without drawing appreciable energy from the test circuit. Many investigators, both here and abroad, are now studying the phenomena of lightning with renewed interest, and considerable benefit is certain to come from these studies.

Ferromagnetism

During the past year notable advances have been made in our understanding of ferromagnetism, principal among which may be noted:

1. Studies of single crystals of iron and of nickel have shown remarkable magnetic properties different from those obtained in multi-crystalline materials. The principal contributors in this field have been Honda, Webster, Gerlach, and Sucksmith.

2. Studies of magnetostriction in permalloy by

McKeehan have indicated that this phenomenon plays a much more important role in ferromagnetism than had previously been appreciated, and that hysteresis is very definitely related to magnetostriction. Work by Wedensky and Simanow and by S. R. Williams confirms the existence of such a relation.

3. Studies have been made on the magnetic properties of iron and magnetite at radio frequencies by Wait. His results throw doubt on the results previously reported by Arkadiew and his collaborators.

4. Studies of the specific heat of ferromagnetic metals by Sucksmith and of the closely related magneto-caloric effect by Weiss throw some light on the relations between thermal and magnetic energy.

A very notable contribution to the literature of ferromagnetism which is of particular interest to electrical engineers is Thomas Spooner's book on the properties and testing of magnetic materials.

High-Voltage Research

In the realm of high-voltage research, steady progress has been made. Corona has been studied up to potentials of 1,000,000 volts. Spark-gap measurements have been extended to 2,000,000 volts. The past year saw the first 220-kv. transmission system in the East put into operation (in Pennsylvania).

The use of the ground wire seems to find increasing favor as a means of decreasing the number of serious impulses occurring on transmission systems during lightning storms. Laboratory tests have shown quantitatively the benefits to be derived from the use of the ground wire under various conditions. The shielding of buildings and other structures from the effects of lightning has also been studied.

Several high-voltage laboratories are now available for research and test purposes, the latest being the new 2,000,000-volt Ryan Laboratory at Stanford University.

General Progress in Electrophysics

With the discovery of X-rays and radioactive substances, some 30 years ago, the progress in physics has been phenomenal, and it is not possible even to enumerate briefly the important contributions which have been made within the last year or two, especially in the domain of our knowledge of the fine structure of spectral lines. These contributions follow the trend of ideas, previously established, with respect to the individual electronic orbits which determine the atomic and molecular structure of matter and the ultimate nature of various forms of radiation and other forms of energy.

An authoritative and monumental work on modern physics is now appearing under the title, *Handbuch der Physik*, edited by Geiger and Scheel, in 24 large volumes (Springer, Berlin). Scores of prominent physicists are contributing to this work. Numerous special books are also available on branches of physics of interest to our profession, such as X-rays, spectroscopy, ionization, dielectrics, photoelectricity, molecular structure, radiations, chemical physics, etc.

Those who wish to get a bird's-eye view on modern developments in physics should read Darrow's "Introduction to Contemporary Physics" (Van Nostrand) and his serial articles in the current issues of the *Bell System Technical Journal*. See also R. A. Millikan, "The Last Fifteen Years of Physics," *Amer. Philos. Soc. Proc.*, 65.2, pp. 68-78, 1926.

By following certain portions of *Science Abstracts*, Section A, one may readily keep in touch with the progress of any particular branch of physics in which one is interested. For work done in this country, the abstracts of papers presented before the American Physical Society and published in its bulletin should be consulted. This bulletin appears separately and is also subsequently reprinted in the *Physical Review*. Publications of the National Academy of Sciences, Franklin Institute, American Philosophical Society, Bell System, etc., will also be found useful.

Vladimir Karapetoff, *Chairman*.

Discussion

R. W. Sorensen: The 1927 Pacific Coast Convention papers will include reports of work done in a study of the characteristics of lightning and devising means of protecting oil reservoirs against lightning strokes. One of the two papers to be presented at that time is the result of work done in the research laboratories of California Institute of Technology, a group of people who wish protection for oil-storage reservoirs providing funds for this definite piece of research work. These funds have been used up and certain protective plans for oil reservoirs prescribed, but there remains much to be done in making a comprehensive study of lightning and protection against it. Also this is one of the types of problems which, if properly financed, could well be carried out by one or more college staffs. Research on such a problem should not be limited to one or two laboratories and their respective groups of research men, but we should have a number of field observation crews and a number of laboratory groups making studies about lightning. It is my hope that a way will be found for men interested in the subject of lightning and provided with high-voltage equipment to do experimental work at our colleges in order that we may train students for this kind of work by permitting members of the faculty and student body to have a part in the work.

I am much encouraged by the work already done. Observers are coming more nearly into accord as to what lightning phenomena are and how to protect against the destructive nature of lightning; but may I, in closing, urge that a comprehensive program be financed in such a way as to enable several college laboratories, as well as the high-voltage laboratories maintained by industrial organizations, to have a part in carrying out these investigations.

People whose eyes tire easily should try daylight lamps according to the Bureau of Standards at Washington. The Bureau has made certain observations which lead it to conclude that some individuals need this particular type of lamp for night reading and that if many are of this type "it is apparent there would be a great field of usefulness for artificial daylight in increasing human happiness and efficiency."

Economic Aspects of Electricity in Mining Work

Annual Report of Committee on Applications to Mining*

To the Board of Directors:

The applications of electricity in the mining industry, especially in coal mining, have shown a marked increase during the past year, due principally to the fact that its use is an important element in the solution of the problem of high mining costs. These adverse economic conditions have forcibly brought to the attention of mine managers the necessity of replacing expensive labor by electrically operated mechanical devices.

Coal loading machinery operated by electricity has demonstrated its entire practicability and has shown a saving of 25 to 35 cents per ton in mining costs. Much study still remains to be made concerning the question of coordinating machine loading and mining methods. This new and concentrated use of power in a certain section of a mine means a complete reconstruction of the power system, in order to obtain a good voltage regulation for not only the new equipment but for the old as well.

An armoured cable capable of delivering 3000 kw. of power at 4000 volts and 80 per cent power factor has been recently installed in a metal mine shaft 5000 ft. deep. The lowering of a cable of this size into a vertical shaft and its proper clamping to the supporting timbers were problems solved in delivering a big block of power to the bottom of a deep shaft.

In gaseous coal mines where ventilating fans are electrically operated by power obtained from extensive high-tension systems, it is necessary to provide an emergency source of power to operate the fan in case of the failure of the normal power supply. A successful installation of this type was placed in service during the past year, and it consists of a gasoline-engine-driven generator set which will supply power to the emergency motor connected to the double extending fan shaft. After a failure of the normal source of power, 30 sec. are required to automatically start the gas engine set and restore normal fan service.

The use of storage battery power trucks with a capacity of about 150 kw-hr. for operating coal cutting machinery is increasing. Installations of this type result in an increase in the number of places cut and an improved load factor of the power system, providing good judgment is exercised in selecting the time at which the battery is charged. In gaseous mines, the use of battery power not only for cutting, but for pumping and hauling as well, introduces an element of safety heretofore unobtainable.

Automatic starting equipment has been successfully applied to pumping plants, converting apparatus and fans, and lately, air compressors have been operated without attendants. Successful applications of automatic starting equipment have been made to two- and three-speed induction motors, notwithstanding the complicated electrical layout which an installation of this type involves.

Improvements in the haulage systems are being effected by the use of gathering locomotives designed to operate at a slower speed than during the past. The converting equipment required for haulage locomotives is being placed nearer to the load centers, thereby improving the voltage regulation. In mines where a very large tonnage must be transported through a single outlet, belt conveyors have been installed which have demonstrated their value under the above mentioned special conditions.

Many installations of electrical shovels have been made in the metal mining industry, and more recently, the coal mining industry is using this type of shovel. The Ward Leonard control on the large shovels and a motor-generator set with d-c. motors on the smaller shovels show the trend in the electrical apparatus used on shovels.

The work of the United States Bureau of Mines in listing the permissible electrical equipment for use in gaseous mines is one which deserves the commendation and support of all those interested in the safe operation of coal mines. The list is growing rapidly and at the present time it is so complete that a mine manager may select permissible equipment for practically every application in mining. The equipment shows good design and a low maintenance cost. The fact that the Bureau of Mines has approved as much equipment during the past two years as was approved during the previous 10 years is proof sufficient that its work is being valued by the mining industry.

That electricity is being applied in the development of mine safety appliances is shown in the recently developed methane detecting device. Briefly, it consists of a platinum filament mounted on the end of a stick, a battery, and an indicator carried on the inspector's belt. Current from the battery is passed through the filament and it is heated to a constant temperature. The presence of methane or other hydrocarbon gas around the filament increases its temperature

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* Committee on Applications to Mining Work:

W. H. Lesser, Chairman

M. C. Benedict,	Carl Lee,	W. F. Schwedes,
F. N. Bosson,	John A. Malady,	E. D. Stewart,
Graham Bright,	Charles H. Matthews,	F. L. Stone,
L. C. Ilsley,	F. C. Nicholson,	W. A. Thomas,
G. M. Kennedy,	H. F. Pigg,	E. B. Wagner,
R. L. Kingsland,	L. L. Quigley,	J. F. Wiggert,
A. B. Kiser,	Herbert S. Sands,	C. D. Woodward.

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927.

and this is indicated on a dial graduated to show the amount of methane in the air. Indicators may be permanently located in an airway and can be wired to a device in the mine office which will ring a bell when the methane rises above the point which is considered safe. Explosions are prevented by protecting the coil by gauze bonnets such as are used in the Davy safety lamp. The results obtained from this apparatus are very satisfactory.

Further development of the miner's cap lamp has doubled the light available. Judging from the increased efficiency obtained from factory workers when the illumination is increased, there is no doubt that the increase in light furnished to the workers in the "darkest factory" in the world will result in an increase in safety, and efficiency as well.

When one considers that 80 per cent of the American mines are electrified, it seems reasonable to conclude that this accomplishment has been helpful in reducing operating costs.

Such a general adoption of electrical power by mines where the equipment is subjected to damp and gaseous mine air shows that the manufacturers have done their part in designing equipment to meet the conditions. The commercial power companies have also helped in that they are usually in a position to serve a mine with power even if it is located in an isolated section.

W. H. LESSER, *Chairman.*

High-Frequency Measurements

Report of Committee on Instruments and Measurements

To the Board of Directors:

Three branches of the field of electrical measurements in which the demands of industry have stimulated new, improved and more precise methods and means of measurement are:—electric power and energy, dielectrics, and high frequency. The first two items were covered in the report of the committee for 1925-26 and in the symposium on dielectric measurements conducted at the Niagara Falls Regional Meeting of the Northeastern District, May, 1926.

HIGH-FREQUENCY MEASUREMENTS

This year's activity has been focussed on the matter of measurement of high-frequency quantities arising principally in the field of carrier telephony and radio. The committee, functioning largely through a subcommittee consisting of Messrs. H. M. Turner, Chairman, E. D. Doyle, Melville Eastham, W. N. Goodwin, Jr. and B. W. St. Clair, arranged for the presentation of a series of papers at the Pittsfield Regional Meeting of the First District (May 25-28, 1927).

A list of these papers and a resumé of the information in these papers are included as part of this report under the heading "Symposium on High-Frequency Measurements."

ELECTRICAL MEASUREMENT OF PHYSICAL VALUES

The committee has also continued, through a subcommittee of one, (namely Mr. P. A. Borden), the extension of the bibliography of articles in other periodicals dealing with the application of electrical methods to the measurement of other than purely electrical quantities. This bibliography is submitted as part of this report.

REMOTE METERING

There has been formed this year a new subcommittee to survey the field of distant indications of electrical quantities. This committee consists of Messrs. E. I. Rutan, R. T. Pierce, and P. A. Borden, and it will report at a later date.

A. E. KNOWLTON, *Chairman.*

SYMPOSIUM ON HIGH-FREQUENCY MEASUREMENTS

The following article consists of a resumé of a series of fifteen papers dealing with measurements at high frequencies. The study of this subject, the preparation of these papers and their presentation, will constitute the major activity of the Committee on Instruments and Measurements during the year 1926-27. The papers are to be presented at the Regional Meeting in Pittsfield, Mass., May 25, 1927. Complete copies may be obtained from Institute headquarters. The papers are as follows:

1. *Notes on the Use of a Radio-Frequency Voltmeter,* by W. N. Goodwin, Jr.
2. *Substitution Method for the Determination of Resistance of Inductors and Capacitors at Radio Frequencies,* by C. T. Burke.
3. *Condenser Shunt for Measurement of High-Frequency Currents of Large Magnitude,* by Alexander Nyman.
4. *Radio-Frequency Current Transformers,* by Paul MacGahan.
5. *Methods for the Measurement of Radio Field Strengths,* by C. R. Englund and H. T. Friis.
6. *The Quantitative Determination of Radio Receiver Performance,* by H. D. Oakley.
7. *High-Frequency Measurements of Communication Lines,* by H. A. Affel and J. T. O'Leary.
8. *Methods of Measuring the Insulation of Telephone Lines at High Frequencies,* by E. I. Green.
9. *High-Frequency Measurement of Communication Apparatus,* by W. J. Shackleton and J. G. Ferguson.
10. *Impedance of a Non-Linear Circuit Element,* by E. Petersen.

11. *Empirical Analysis of Complex Electric Waves,* by J. W. Horton.

12. *A New Thermionic Voltmeter,* by S. C. Hoare.

13. *The Oscilloscope: A Stabilized Cathode Ray Oscillograph with Linear Tome Axis,* by Frederick Bedell and H. J. Reich.

14. *Sensitivity Characteristics of a Low-Frequency Bridge Network,* by P. G. Edwards and H. W. Herrington.

15. *Microammeter Indication of High-Frequency Bridge Balance,* by H. M. Turner.

The committee feels that these papers reflect the latest development in the methods of measurement of quantities associated with frequencies ranging from those just above power and ordinary telephone frequencies through those used in radio communication.

The instruments commonly employed in measurements at ordinary power frequency have very definite limitations when used at the higher frequencies. Also it is a matter of common knowledge that measurements of circuit properties under the higher frequencies cannot in general, be made satisfactorily by direct determination of current and voltage drop in a series arrangement. Much of the progress in the field of high-frequency measurements has been in the direction of bridge modifications, adaptation of the electron tube to measurement circuits, and also the improvement of thermocouple type instruments.

Instruments for Radio Frequencies

A shielded thermocouple type voltmeter for radio frequencies was described by L. T. Wilson in the 1924 Transactions. The current consumption varies from 2 to 8 milliamperes for the conductive circuit of the instrument and a quadrature component for shield-charging of the same order of magnitude. Subsequent investigation during the development of the instrument have shown that in order that the inherent precision of the instrument shall be realized, the effect of inductance and capacitance in the connections must be avoided by observance of careful technique. Thus in measuring the effective resistance of a reactor, the low-potential section of the measuring circuit should be carefully grounded and the high-potential section kept short and clear of solid dielectrics and consequent stray loss.

In measuring the R and L of a broadcast tuning coil, for example: It is connected in series with a 500-m. m. f. condenser, a 100-milliampere ammeter and a 1.2-ohm resistor (say 2 in. of 0.0065-in. manganin) the latter serving as conductive coupler with an oscillator 10-watt or larger. The drop across the resistor as indicated by the voltmeter will be of the order of three volts when the measuring circuit is tuned to sharp resonance. The effective resistance of the coil is less than E/I by the amount of milliammeter and condenser resistances. The inductance of the coil is computed from the resonance formula and the capacity setting of the condenser. The frequency error of this device is about 1 per cent for frequencies of the order of 1500 kilocycles. (See paper No. 1).

Circuit constants of capacitors and inductors are, in one method, of a substitution type, found by resonating them in a series circuit and using as an indicator a crystal in series with a d-c. microammeter, the combination shunted across a small inductance in the series circuit.

The resistance of an inductor is found in the value of a non-reactive resistor substituted for the inductor in a circuit tuned in both cases to resonance by adjustment of a capacitor having negligible equivalent series resistance. The inductance is found in terms of the quotient of difference and product of the capacities required for resonance. Similarly, the capacitance and resistance of a capacitor are found in terms of the change in resistance and capacitance between resonance, with and resonance without the capacitor in question. (See paper No. 2).

In the measurement of high-frequency current of more than 10 amperes the hot wire instrument is not feasible because the size and resistance tend to become prohibitive. The thermocouple ammeters for larger ranges than 100 amperes become very expensive on account of considerations of skin effect and size of heating element. Iron-cored current transformers are satisfactory up to 500 kilocycles but for much higher frequencies the difficulties in design increase.

A method has been developed which employs a hot-wire or thermocouple ammeter in series with a relatively small condenser and the combination in parallel with a large condenser shunt. The error due to the thermocouple resistance need not exceed 0.5 per cent with frequencies up to 6000 kilocycles and satisfactory commercial measurements are feasible up to 60,000 kilocycles. Unit assembly of the shunt condenser readily permits the provision of several current ranges,—say 50, 100, 200 amperes, the thermocouple instrument in each case having a 0.25-ampere rating. Care must be taken to avoid losses from resonance of the closed circuit at some harmonic of the fundamental. The absolute calibration of the arrangement presents difficulty even by means of a calorimeter ammeter because of the uncertainty about high-frequency resistance and effect of distributed capacity. The condenser shunt is apparently entitled to greater confidence than a direct thermal determination. (See paper No. 3).

For the measurement of large currents at high frequency, there are also available current transformers of the through-type with secondary rated at one ampere; the indicator is usually a thermocouple type ammeter. (See paper No. 4).

Radio Field-Strength and Receiving Sets

The vacuum tube used as detector, amplifier and voltmeter is the basis of sensitive comparator methods for determining radio field strengths at frequencies below 1000 kc. in the customary unit of micro volts per meter

The loop-antenna is employed in preference to the open-antenna and no indirect evidence has appeared which places in doubt the value of equivalent effective height computed for the loops used. Both the $I R$ drop and mutual-inductance voltage methods are employed for introducing into the antenna the sinusoidal comparison voltage; the resistance method is preferred because its reactance is of less concern than the resistance of a mutual inductance and also it serves admirably as a terminal impedance for a constant impedance attenuation network. Shielding is easier with resistance coupling.

For frequencies higher than 1000 kc. the above method becomes unworkable and a double-detection type of receiver is used after calibration as a vacuum tube voltmeter. The received field strength is evaluated in terms of three measured attenuation factors, the received signal voltage and the loop effective height. Static energy and static "noise value" are of interest; continuous static is readily measurable in terms of the telegraph signal strength masked by it. The enormous variability of usual static has prompted measuring it by noting the gain of the receiving set necessary to maintain constant static output. A non-restoring type of deflection instrument comparable to a fluxmeter has merit in summing the received energy over a definite interval. (See paper No. 5).

The problems of measurement of the common electrical properties of the individual elements and of circuit units of radio receiving sets having been dealt with, there are remaining those factors of set performance which differentiate sets with respect to their selectivity, sensitivity, fidelity of reproduction and reradiation. Each of these attributes of a completed set have been reduced to a quantitative definition and measuring method which evaluates them in terms of output voltage obtained on response to the input from a controlled signal generator. Thus sensitivity is determined as the ratio of output voltage to input field strength at various output voltages and input frequencies. Dimensional analysis of the expressed ratio results in reduction to length units; therefore, sensitivities are expressed in meters. Selectivity is determined in terms of the input field strength required to maintain a constant minimum value of output voltage for the requisite range of frequencies. Quality performance is expressed as the ratio of output voltage at the various modulation frequencies, the antenna voltage and degree of modulation being maintained constant. Radiation is expressed in meter-amperes, the meters being the antenna height and the amperes that value of current required to establish various output voltages in a detector of known sensitivity when the latter is supplied with the radiation output of the receiving set. (See paper No. 6).

Telephone Carrier-Frequency Measurements

In the field of telephone carrier frequencies, the line characteristics of chief interest are attenuation, impedance and cross-talk for frequencies up to about 50,000 cycles. Apparatus for field and laboratory measurement of these quantities has been developed and standardized on a unit basis. The units consist of oscillator, detector-amplifier, impedance-bridge, thermomilliammeter, variable attenuator, cross-talk set and frequency meter. The oscillator is a vacuum-tube and tuning circuit giving 0.4 to 0.7 watts maximum at frequencies from 100 to 50,000 cycles and above 3000 cycles has no harmonics of more than 10 per cent of the fundamental amplitude. The detector-amplifier is adapted to both aural and visual balancing or indication. The impedance bridge is of the balancing or differential coil type. The thermomilliameter carries its own d-c. calibrating circuit and provides for the use of three thermocouples of a range of characteristics to cover a current range from 0.2 to 50 milliamperes. The attenuator is a network of known loss and terminal impedance and the cross-talk-set is a similar attenuator adapted to cross-talk measurements of the order of 10^{-6} times the transmitted currents. The frequency meter is a resonance bridge. Attenuation measurements made on the current-transmitted versus current-received method are possible for energy ratios up to 30×10^6 to an accuracy of about 3 per cent. Impedance measurements are of importance in connection with non-homogeneous lines and these are generally made on the line after terminating it in its characteristic impedance, usually a resistance of about 600 ohms; the results indicate the efficacy of loading to meet carrier-current operation. Avoidance of cross-talk with carrier-frequency operation presents many difficulties and necessitates a highly refined system of transpositions; the cross-talk measurements made to determine the effectiveness of the transpositions are a specialized form of attenuation measurements, *i. e.*, attenuation to cross-talk must be high and to line transmission, low.

It is by such a system of measurement that a telephone circuit is tested for its quality after the necessary modifications have been made in preparation for carrier-current operation. (See paper No. 7).

A substantial part of the increased attenuation at carrier frequencies is due to skin effect of the conductors, and the leakage conductance of the insulators is found to increase rapidly with the frequency; radiation is a negligible factor. It is permissible to attribute to leakage conductance all losses except those of an $I^2 R$ nature in the metallic conductors; the leakage conductance, G, may of course, be derived from measurements of the attenuation but the line would have to be at least 100 mi. in length. A direct measurement of G on a line short enough (250 ft.) to avoid propagation effects and a phase shift of more than five degrees has been made on an experimental line with sufficient comparability to represent the shunt losses in long lines; the line contained 25 poles spaced 7 ft. apart and with

6-in. spacing of the insulators on the crossarms. A certain amount of transposition was resorted to, but the important precautions pertained to the manner of leading the conductors into the test station.

Each circuit is in effect a conductance shunted by a capacitance and thus the equivalent of the leaky condenser; the bridge for the conductance measurements is similar to those employed for the determination of the loss angle or power factor of dielectrics and condensers. The high resistance of a few insulators in parallel would appear to require a correspondingly high value of resistance in the standard side of the bridge but this is avoided by placing a condenser in series with a lesser value of resistance. A method of obtaining continuous record of d-c. leakage has been developed; a similar continuous record of the high-frequency leakage is greatly to be desired but as yet awaits solution. (See paper No. 8).

The performance of communication apparatus depends principally upon its impedance and in the precision and routine measurement of resistance, inductance and capacitance, standards of primary and secondary nature are necessary. The prime standards may well be resistance and frequency and the derived standards those of inductance and capacitance. Self-driven forks (calibrated by phonic wheel for 24-hr. period against Arlington time) can be maintained within 0.001 per cent of 100 cycles. Other frequencies can be compared with the standard by means of the cathode ray oscillograph. Resistance standards must have minimum and constant phase angle; 1000-ohm standards have been constructed with effective inductance not exceeding five microhenrys up to 100 kc.

Secondary standards of capacitance are made with mica dielectric impregnated with paraffin; such condensers can be obtained with temperature coefficient below 0.005 per cent per deg. cent. and with less than 0.1 per cent capacitance variation from 500 cycles to 100 kc. and phase angles less than one minute. Air condensers are feasible for the smaller capacitances. Secondary standards of inductance must be constant and preferably with small external field. Air-cored standards of large inductance involve considerable distributed capacitance; on this account cores of permalloy have been used with considerable success. Secondary standards of resistance in dial form inevitably involve more distributed capacitance than single primary standard resistances.

In the comparison of secondary standards against primary standards, methods which determinate the unknown in terms of circuit constants are preferable to those requiring the measurement of current and voltage. The bridges used must be carefully shielded and the equal ratio arm bridge is to be preferred wherever possible. The bridge circuits in use provide for impedance determinations when direct current is superposed on the high-frequency alternating current; these bridge methods also provide means of measuring flutter (telegraph impulse affecting the telephone frequency inductance of apparatus in the common circuit), transformer ratios, capacitance unbalance, attenuation and gain, and cross-talk. (See paper No. 9.)

The harmonic components of non-sinusoidal quantities create difficulties in the measurement of impedance of circuit-elements of a non-linear nature, where the ratio of instantaneous currents and potentials is not constant throughout the cycle. Vacuum tubes are non-linear as to resistance and iron-cored coils at high flux densities are non-linear as to reactance. In a-c. bridge measurements of such quantities it is found that the measured impedance depends on harmonic factors introduced from the source of supply, the magnitude of the resistance in the bridge ratio arms, the impedances of the detector and of the source of supply to the fundamental frequency and to the possible harmonic frequencies, and also upon the method used in attaining bridge balance. As for the last item, the measured non-linear impedance may well be different if balanced, in one case, against standards of resistance and inductance and, in the other case, balanced against a non-inductive resistance after establishing resonance with a standard capacity.

It is thus often essential to arrange the measuring circuit so that the impedance or other quantity measured shall be characteristic of the non-linear device and not of the bridge and supply network. The complicating effect introduced by a non-sinsuoidal impressed potential wave is readily removed by the use of a frequency-selective circuit between the source and the measuring network. The complicating effect of harmonics arising out of the non-linear reaction of the element under measurement may be suppressed in two ways,—one, a modification of the usual bridge method and the other, an a-c. potentiometer method.

In the modified bridge method, two balanced high-inductance coils with high-coupling are inserted in the 1:1 ratio bridge arms. The fundamental fluxes neutralize but the harmonic components of current encounter the series-aiding impedance and are effectually suppressed. In the a-c. potentiometer method the harmonics are suppressed by a filter of low impedance to the fundamental and high impedance to the harmonics developed in the non-linear element. Further modifications make possible the determination of the non-linear characteristics of the element without suppressing the harmonic current flow. (See paper No. 10).

In the transmission of speech it is not only essential that the circuit possess prescribed reactions to steady state conditions but also that it fulfill certain other limitations upon transient conditions. The oscillograph is inadequate to the analysis of the couples waves encountered in, for example, the multi-channel repeater employed in carrier telephone systems and other means of analysis had to be devised. Any distortion by amplifiers or circuit elements results in the

development of new frequencies that are multiples of the components of the impressed wave or are algebraic combinations of those components; these extraneous components may call for detection and measurement when their amplitude is even as low as 0.1 per cent or less of the true signal components. The heterodyne beat method is found useful in such detection and measurement; by a d-c. indicator in the plate circuit of a biased grid tube the amplitude of the d-c. component is directly determined. The same indicator will by relatively slow periodic change in deflection show by a beat method the presence of a minute component of a particular difference-frequency when the oscillator frequency is brought close to the frequency of the component. The method does not lend itself readily to a quantitative determination however.

Practically all analyzers for waves of small amplitude are modifications of the elementary form in which a selective circuit couples a vacuum tube amplifier to the circuit under investigation. Whether the voltage drop across L or C be chosen for application to the grid of the detector depends upon the frequency of the components sought; L for low, and C for high frequencies. The procedure is tedious and long if a wide range of frequencies are sought and there has been developed a device for automatically tuning over the desired range and automatically recording the amplitudes of discovered components. Means are also available for examining the variation of a single component of a complex wave as conditions affecting it are varied; the required selectivity is attained by employing several analyzers in tandem.

For more exacting requirements even the above method is inadequate and for such cases a heterodyne analyzer has been developed; thereby the frequency range to be examined is translated to a lower position of the frequency scale with the advantage of greater fractional separation between components. (See paper No. 11).

Instruments for Moderately High Frequencies

A vacuum tube voltmeter has been developed in which the plate impedance forms one arm of a Wheatstone bridge. With zero voltage impressed upon the grid-filament circuit of the tube the bridge is initially balanced by means of an adjustable resistance, the bridge indicator then reading zero. When an unknown voltage either alternating or direct is then impressed upon the grid-filament the plate-impedance changes, and the bridge balance is disturbed; the resulting deflection of the bridge indicator is a direct indication, after appropriate calibration, of the voltage impressed on the grid filament. (See paper No. 12).

Professor Bedell describes a method for producing stationary curves on the screen of a cathode ray oscillograph and establishing a linear time axis which involves the use of an auxiliary circuit consisting of a source of constant voltage, a neon gas-filled lamp and an electron-tube arranged in the general form of a bridge. The voltage across a portion of this circuit, which varies directly with time, is connected across one pair of deflecting plates of the oscillograph tube and in this way establishes a linear time axis. By means of a motor-driven distributor, the other pair of deflecting plates is connected first to one part of a circuit and then to another, thus making it possible to study several phenomena simultaneously. (See paper No. 13).

The employment of very low frequencies (say three or four cycles per second) involves in some respects as much difficulty as the higher frequencies. The problem of locating opens in telephone cable conductors involves the determination of impedances; a study has been made of the degree of accuracy and sensitivity obtainable in impedance measurement with different frequencies of supply voltage. For long cables the input impedance is a hyperbolic rather than linear function of the characteristic impedance; the error in impedance measurement arising from this functional departure proves to be least for the lower frequencies. On the other hand, the bridge sensitivity is improved by somewhat higher frequencies. A thorough mathematical and experimental analysis of the sensitivity of impedance measurement of cable fault locations up to 70 mi., by means of a de Sauty bridge, indicates the desirability of using frequencies of the order of four cycles. The sensitivity is further increased by controlling the phase of the field excitation of the bridge galvanometer. Use of such low frequencies as four cycles per second is not common and the generating apparatus, bridge, detector, and graphical treatment of errors and sensitivity of measurement of impedances at this frequency are of interest in a report on measurements under other than power frequencies. (See paper No. 14).

The telephone receiver, due to its simplicity, sensitivity and convenience, has been widely used for determining a-c. bridge balance and under favorable conditions is quite satisfactory. The aural method, however, involving as it does the receiver associated with the ear, has two serious limitations; first, it can be used only where there is very little extraneous noise and second, the frequency range for best operation is restricted to a band of, say, from 200 to 2000 cycles unless a heterodyne scheme is adopted.

A visual method has been devised using a d-c. microammeter in the plate circuit of an electron tube rectifier, associated with one or more stages of amplification, which gives maximum reading for a state of balance, thereby permitting the use of a sensitive meter and at the same time making it fool proof. A large bridge unbalance reduces the deflection to nearly zero and as balance is approached it increases. No change in reading on short-circuiting the indicator terminals of the bridge, which would correspond to zero voltage, shows definitely a perfect balance. This method not only completely overcomes the limitations of the aural

method, but also renders a quantitative determination of the degree of unbalance. (See paper No. 15).

Electrical Measurement of Physical Values

By Perry A. Borden

(Supplementary Bibliography)

The following bibliography, prepared at the instance of the Committee on Instruments and Measurements, is supplementary to that accompanying the writer's paper on the above subject published in the Transactions of the A. I. E. E. Vol. XLIV (1925) p. 238. While most of the articles referred to have appeared in the technical press during the current year, some are of earlier dates, and a few references are made to standard works on electrical measurement. The arrangement of headings has been retained as in the original paper, but the references are not numbered.

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Electrical Reproduction from Phonograph Records

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Synopsis.—*A new and improved tool generally means new or improved accomplishments. Great improvements in sound recording and reproduction have been made possible by the thermionic amplifier.*

Electrical reproduction may be considered in three steps, (1) generation of a voltage by the vibrations of the needle, (2) amplification, (3) conversion of electrical power into sound. The first of these steps involves some interesting mechanical and electrical problems, and it is with these that the paper primarily deals, the problems of amplification and loud speaker design having been discussed in earlier publications to which references are given. Several types of phonograph "pick up" are possible; electrostatic, piezoelectric, electromagnetic, and variable resistance or microphonic. The electromagnetic principle is used in the device now manufactured. Since the moving armature cannot be actually at the needle tip, the little generator must function by transmitting the vibrations from the needle tip through a more or less flexible structure to the armature. Vibrations are inevitably transmitted, but when the requirements of freedom from appreciable distortion and maximum possible output are added, extreme care in design becomes necessary. An analysis is given of the mechanical behavior of the present model of reproducer.

MANY interesting improvements have been made recently in methods for recording and reproducing sound, which have resulted in truer and more pleasing reproduction. These have involved the use of electrical means in recording, while both electrical and direct or mechanical systems are being used with good results for reproduction. A discussion of some of the problems arising in an electrical system of reproduction, seems warranted in view of the widespread interest in such questions and of the fundamental nature of some of the mechanical problems involved.

Mechanical and Electrical Systems Compared. The inherent advantage of electrical method of phonographic recording and reproduction, as compared with the older direct methods, lies in the fact that the electrical methods can make use of amplifiers. In the old system of recording, the cutting tool was mechanically connected to a diaphragm which was actuated by sound waves. The power available to give the necessary vibrations to the tool was thus limited to what could be collected from the original sound. In the case of electrical recording the power for vibrating the tool may be made as great as needed. This does not necessarily mean louder records or greater amplitude of vibrations. In acoustic apparatus extreme sensitivity is generally purchased at the expense of quality. In order to get sufficient amplitudes of cutting tool vibration, a horn was used to concentrate the sound waves, and a resonant diaphragm was employed. Both of these introduce distortion. In electrical recording, a sound pick up or transmitter without a horn is used. Its electrical output is small, but can be amplified without appreciable distortion, and relatively large forces can be applied magnetically to the cutting tool, which may now be heavily damped, thereby reducing its tendency to respond more to certain frequencies in the musical scale than to others.

When we come to the problem of reproduction from the record, the possibility of amplification does not give so great an advantage to the electrical system, as in the recording, because the reproducing needle, unlike the sound waves with which we started, can deliver considerable power, or apply large forces to the object which it is required to vibrate. This power at the reproducing needle is, of course, derived from the rotation of the record. In fact, cutting a record and then playing it may be regarded as a method of power amplification. In the old method of cutting and reproduction the power output in sound from the phonograph is normally many times the power collected by the horn used in recording.

Both the mechanical and electrical systems can be so designed as to give a very high order of quality in reproduction. The advantage of the mechanical system is its simplicity. The advantages of the electrical system are its flexibility, ease of adjusting loudness, and the possibility of obtaining greater volume of sound, where this is desired and the apparatus is designed accordingly.

Electrical reproduction may be considered in three steps, (1) the vibration of the needle must be made to generate a voltage whose wave form corresponds to the wave in the groove, (2) this voltage is amplified, and (3) an electrical loud speaker converts electrical power back into sound. The design of amplifiers and loud speakers has been discussed in earlier papers[2]. The present paper will, therefore, deal principally with the device in which the vibration of the needle generates the voltage which is to be supplied to the amplifier.

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2. *Design of Non-Distorting Power Amplifiers*, Edward W. Kellogg, A. I. E. E. TRANS., Vol. 44, 1925, p. 302.

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See also bibliography on amplifiers and loud speakers at end of paper.

Possible Types of Reproducer

The same principles by which diaphragm vibrations in a transmitter are made to produce voice currents, may be applied to the case of the phonograph reproducer. Many types of transmitters have been used, among which are the magnetophone (Bell's first transmitter as well as receiver) the variable resistance transmitter such as in general use in telephony, the condenser transmitter[3] which is used in broadcasting stations, and a transmitter making use of a piezoelectric[4] crystal. These transmitters may be classified as of two types: (1) those in which the output voltage is proportional to the deflection, and (2) those in which the output voltage depends on the velocity of diaphragm movement. The carbon microphone, condenser and piezoelectric transmitters as generally used are of the first type, while the magnetophone belongs to the second or velocity type. The condenser transmitter, for example, is kept charged through a very high resistance so that the charge upon the plates cannot change appreciably during an audio cycle. The voltage across the condenser then varies inversely as the capacity, or directly as the plate spacing. The voltage thus obtained which is applied to the grid of an amplifier tube is proportional to diaphragm deflection, independent of frequency except for frequencies so low that the condenser reactance is considerable compared with the leak resistance (for practical purposes we may say equal to the leak resistance). The same considerations apply to the piezoelectric crystal which may be regarded as a condenser of constant capacity but variable charge, the charge depending on the mechanical force applied to the crystal. On the other hand, both the condenser transmitter and the piezoelectric crystal may be made to act as velocity devices by using leaks whose resistance is low compared with the capacity reactance of the condenser throughout the essential frequency range. In this case the charge flows freely back and forth through the resistance, and the current (or voltage across the leak resistance) is proportional to the rate of change of charge which in turn is proportional to the diaphragm velocity. The magnetic transmitter works on the principle of changing the magnetic flux through a coil. Its open circuit voltage is proportional to the rate of change of the flux, and this again depends on velocity of movement. In terms of sine waves, the deflection devices (type No. 1) give a voltage proportional to ampl tude independent of frequency, while the velocity devices (type No. 2) give a voltage proportional to amplitude multiplied by frequency.

3. See papers on the Condenser Transmitter by E. C. Wente, *Phys. Rev.*, *X-1*, p. 39 XI, p. 450 XIX.

4. H. and P. Curie, *Compt. Rend.*, 91, pages 294 and 383, 1880.

J. Valasek "The Piezo-electric Activity of Rochelle Salt," *Phys. Rev.*, Vol. 19, p. 478, 1922.

A. Mc L. Nicolson, *The Piezoelectric Effect in the Composite Rochelle Salt Crystal*, A. I. E. E., Trans., Vol. 37, 1919, p. 1315.

W. G. Cady, *I. R. E.*, Apr. 1922.

Which of these types of device should we choose for a phonograph reproducer? If the system by which the record is cut is so designed that the deflection of the cutting point is proportional to the original sound wave pressure, then a deflection type reproducer is required. If the record is cut by a tool whose instantaneous velocity is proportional to the sound wave pressure, we shall require a velocity type reproducer. Both systems are equally correct from the standpoint that if their conditions are complied with, distortionless reproduction will result. The choice can, therefore, rest on such considerations as scratch noise ratio, wearing qualities of record, interchangeability of records, and designing a practical device which performs in accordance with the theoretical requirements. By interchangeability of records is meant that it is desirable that the electrical reproducing system shall not only give good results with records that are especially cut for it, but so far as possible give pleasing results with records cut by the old process, and the records which are correctly cut for electrical reproduction should sound well when played on a horn type machine. This requirement is most nearly met by the velocity system of cutting and reproducing. When a diaphragm is placed at the end of a long pipe it produces sound wave pressures in the pipe proportional to the diaphragm velocity. If, instead of a pipe, the diaphragm works into a horn of the usual (approximately exponential) shape, the same relation holds, very nearly, over most of the frequency range, the difference being that below a certain frequency the sound radiation from the horn drops to almost nothing[5]. If the needle motion is properly imparted to the diaphragm, a phonograph of the horn type may be regarded as a device giving output sound pressure proportional to needle velocity, except that its response is limited to frequencies above a certain value. In some of the new designs employing long slowly expanding horns, the range of response has been greatly extended in the direction of response to lower tones, this change plus the reduction of resonances in the system makes of the horn phonograph a machine which holds very closely to the relation—output sound pressure proportional to needle velocity. It is, therefore, clear that if the electrical reproducing system is to be such that records may be satisfactorily interchanged, it must work on the velocity principle. It is not apparent that in respect to wear of records and scratch ratio a system in which output depended on deflection rather than velocity would have any advantages to offset the disadvantage of not having the records interchangeable.

Of the possible devices giving voltage proportional to needle velocity, the magnetic and the piezoelectric

5. *Function and Design of Horns for Loud Speakers*, by C. R. Hanna and J. Slepian, A. I. E. E., Trans. Vol. 43, 1924, p 393.

The Performance and Theory of Loud Speaker Horns, by A. N. Goldsmith and John P. Minton, *I. R. E. Proceedings* Aug. 1925.

have both been proved practicable, and the condenser is unquestionably a possibility. A very satisfactory design employing a piezoelectric crystal was worked out by Mr. Chester W. Rice of the General Electric Company. The magnetic reproducer gave substantially the same results, and was chosen on account of manufacturing considerations. It is the mechanical problems involved in the design of this device which are of especial interest.

The Magnetic Reproducing Device or Phonograph Pick-Up

Fig. 1 shows in outline several possible forms of magnetic reproducer for use with records having laterally cut grooves (as distinguished from grooves of varying depth). In each of these a movement of the needle causes a change in the flux through the coil or coils, and the voltage induced depends on the rate at which this flux changes, or on the velocity of movement of the iron armature. If there are no short-circuited turns, if the winding is electrically unloaded, and if the iron parts are of low reluctance at all frequencies compared with the air-gaps, the faithfulness of reproduction depends entirely on the similarity of motion of the armature and needle point. If the structures were rigid this similarity would be perfect and distortion would be nil.

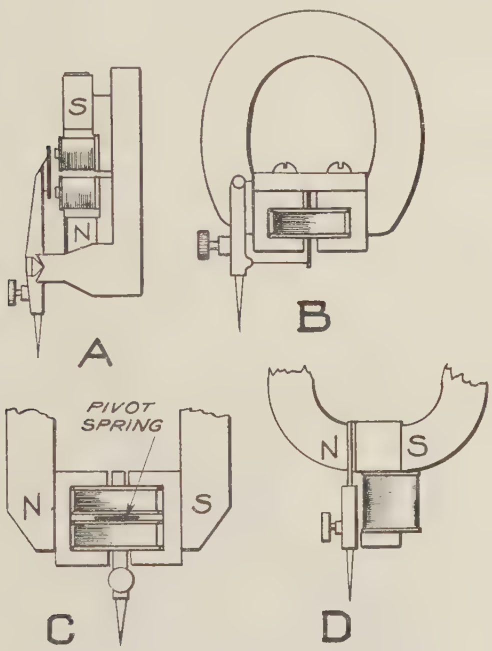
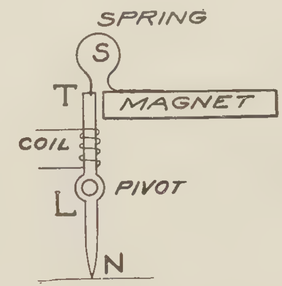


Fig. 1—Several Possible Types of Magnetic Phonograph Pick-Up

Very little power is absorbed by the moving iron armature, for the winding is virtually unloaded, and even if the winding were loaded through a resistance, the power absorption would not be sufficient to produce much damping. There is, however, considerable stiffness in the mounting of the armature, necessary to resist the magnetic pull.

The mechanical problem may then be stated as follows: Given a certain movement of the needle tip, a motion of identical form must be imparted to a small magnetic element at an appreciable distance from the needle tip, displacement of the magnetic element from its main position being resisted by a spring or its equivalent. There are three types of structure by which



Fif. 2—Essential Features of a Magnetic Pick-Up

the vibratory motion might be transmitted and the requirement of identical wave form be fulfilled: (1) A rigid structure (2) a spring potentiometer (3) a filter type or wave transmission structure. Fig. 2 shows a magnetic reproducing device or pick-up in schematic form. The only way in which the motion of the end T can differ in wave form from that at N is by bending of the lever or give at the pivot. In other words, making the system rigid will prevent distortion. But freedom from distortion is also compatible with flexibility in the lever and needle. If the needle point is pushed to one side of its normal position the yield is partly in the lever and partly in the spring S, the amount of motion at T depending on the relative stiffness of the two. I have called this a "spring potentiometer," by analogy with the electrical potentiometer. If two springs are connected in series as indicated in Fig. 3 the motion of the junction point T is a certain fraction of the motion at N. The ratio is only constant, however, if mass plays no appreciable part. If a mass is located at T the motion

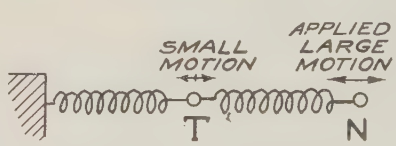


Fig. 3—Spring Potentiometer

of the point T will be practically the same as though there were no mass present, provided the natural frequency determined by the mass in conjunction with the two springs is well above the highest frequency applied at N. The third type of structure by which the motion at N can be accurately reproduced at T is one in which both flexibility and mass are distributed. The distribution need not necessarily be uniform but the masses and flexible elements must have certain relations which depend on the range of frequencies to be transmitted. In this case there is definite wave motion

and progressive phase differences between the motions of the successive parts of the structure. Because the masses and flexible elements are lumped rather than uniformly distributed, the wave motion structure has the properties of a filter, and has been called the "filter type structure" by Messrs. Maxfield and Harrison in their discussion of recording and direct or mechanical phonograph reproduction[6]. If the distance through which it is desired to transmit acoustic vibrations is of the order of several inches it becomes practically impossible to construct a rigid mechanical transmission, or one in which mass plays negligible part. Wave motion becomes inevitable, and to secure distortionless transmission it is necessary to so design the system that the waves will not be reflected. This means a proper proportioning of the mass and flexibility of each part, and the final absorption of the wave energy in a mechanical resistance of the correct value. If these conditions are met there is practically no limit to the distance to which the vibrations may be accurately transmitted. In the case of mechanical reproduction from a laterally cut phonograph record the necessary distance from needle point to diaphragm is too great for a truly rigid connection, while the mechanical resistance necessary for proper wave transmission is obtainable from the reaction of air on the diaphragm. The wave or filter system was, therefore, the logical choice.

For the electromagnetic reproducer on the other hand there appeared to be a possibility of making the distance short enough and the parts light enough so that a good approximation to a rigid structure could be obtained. If this should prove possible, the design would be much simplified, the required exactness of duplication would be reduced and the necessity of obtaining a pure mechanical resistance would be avoided.

In considering the design of a magnetic reproducer it is necessary to choose between several possible types, such as moving-coil as against moving-magnetic armature, center-pivoted or full rocker as against end-pivoted or half rocker, windings on poles as against winding on armature. Several of these possible types are illustrated in Fig. 4.

The moving coil arrangement involves a long air-gap and, therefore, a heavy field magnet. Moreover the mass of the coil is objectionably large. Devices with iron armatures which move toward and away from the poles of a magnet have better possibility of producing a large change of flux interlinkage with a small movement of a small mass.

Again, there is decided choice between the various magnetic armature arrangements. In the first place it is better to place the windings around the armature than around the poles for much of the flux change in the armature involves only a slight shift of the flux from the pole pieces and does not cut all the turns of a coil wound on the pole. Hence we may limit our choice to column III.

Next is the question of single acting vs. double acting or "push pull" arrangements. Comparing k with j of Fig. 4, for example, we may say that adding the two poles on the left hand side of the armature has doubled the magnetic effect which results from a given motion of the armature, for there are just twice as many air-gaps whose reluctance is varied. Moreover, by placing opposite poles on the two sides we have reduced the steady flux which the armature has to carry, leaving only the residual or alternating flux. Hence the armature may actually be lighter in k than in j. Again, the rocker type armature has an advantage over the translation type armature in which both ends move in the same direction. It is only the motion of the ends of the armature opposite the poles which is effective to

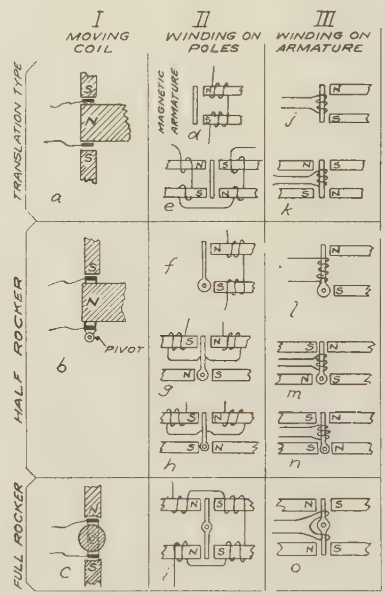


FIG. 4—MAGNETIC SYSTEMS AVAILABLE FOR REPRODUCING DEVICES

produce flux change. In the translation type all parts of the armature move equally, whereas in the rocker type, the middle has only slight motion for a given motion at the ends.

We have now reduced the choice to the half rocker as compared with the full rocker. The middle of the armature of the full rocker is a point of constant magnetic potential. If we imagine the armature cut in two and only the upper end moved, we should still get as much flux change through the upper end of the armature as we did in the full rocker, provided we could keep the lower end of the moving portion at constant magnetic potential. In other words, we might say that in the full rocker type the motion of the upper half gives rise to the flux change and that the motion of the lower end is required to keep the middle at constant magnetic potential. In the half rocker the pivot end of the armature can be kept at *nearly* constant magnetic potential

6. *High Quality Recording and Reproducing of Music and Speech.* J. P. Maxfield and H. C. Harrison, A. I. E. E., Feb. 1926, *Bell System Tech. Jour.*, July, 1926.

by making the reluctance of the air-gaps at this end low compared with that of the gaps at the moving end. For example if the reluctance of the gaps at the pivot end is equal to that of the moving end gaps the flux variation will be half as much as in the full rocker, while if the pivot end gaps have one-fourth the reluctance of the moving end gaps, the flux variation in the armature will be eight-tenths as much as in the full rocker. This assumes negligible magnetic potential consumed in the armature and pole pieces, compared with that used in the gaps. It appears then that the half rocker is not necessarily at great disadvantage compared with the full rocker from the magnetic standpoint, and we shall see that it lends itself better to meeting the mechanical design requirements. The foregoing comparison of magnetic systems does not take into account the possible power output of the winding, nor is the elastic stiffness required to hold the armature in its mean position allowed to weigh in the choice. The comparison is wholly from the standpoint of obtaining the maximum open-circuit voltage with the minimum effective inertia of moving parts.

It is desirable that the magnetic reproducer shall utilize needles of about the size already in use. This means that the needle clamping screw must be within about ⅝ in. of the record. The screw is a potential source of trouble, first because it adds mass to the moving system and secondly because it has its own natural

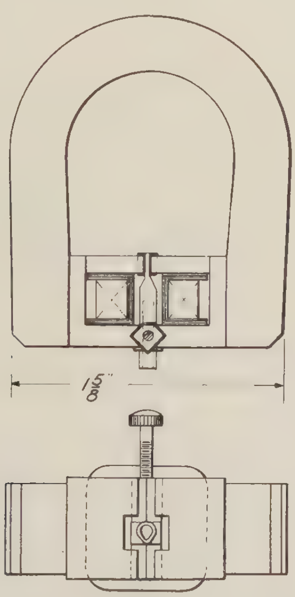


Fig. 5—Magnetic Phonograph Pick-Up as Manufactured

frequency of vibration which reacts on the motion of the armature producing both an anti resonance and a resonance. If the screw is very short and stiff its natural frequency may be high enough to avoid detrimental effect, but the problem may then be to make it conveniently accessible. The types of device shown in Fig. 1 depend on using a short stiff screw. In designs of the type shown in Fig. 1B the set screw was accessible but these devices were found to depart too far from rigid structures, and high-frequency resonances resulted with almost complete loss of the frequencies above the resonance. In the type of reproducer shown in Fig. 1C the set screw is difficult to reach owing to the presence of the coil and pole pieces. Alternatives to the set screw were considered, but a more satisfactory solution appeared to be the location of the screw in the axis of rotation. In this position it can be made as long as desired and no effect of screw resonance has been

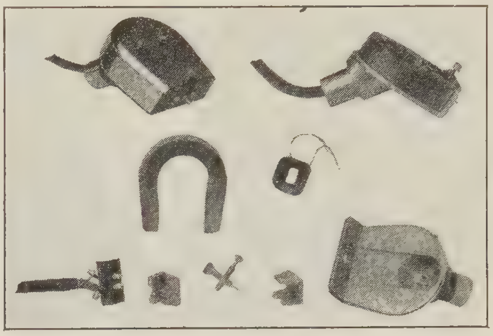


Fig. 6—Magnetic Phonograph Reproducer and Parts

observed. Placing the screw in the axis of rotation practically necessitates the half rocker rather than the full rocker construction, since the length of standard needles is such that the armature cannot extend far enough below the set screw to afford room for a coil and pole pieces.

Fig. 5 and 6 show the construction of a successful design of magnetic reproducer of the half rocker type. The armature is designed to have the smallest possible moment of inertia consistent with an adequate magnetic section and moderately large amplitude of movement of the upper end. In order that the axis of rotation may coincide with the screw and pivot axis at all frequencies, the armature is designed to have the center of gravity of the armature and needle coincide approximately with the pivot. The method of pivoting is unusual. In order that rotation might take place about the screw axis a journal type of bearing was desired, but all rubbing friction must be avoided in acoustic devices if distortion is to be obviated. Hence instead of having the shaft rotate within a journal with sliding friction, a film of rubber is interposed. This permits small rotation in either direction without friction but with a slight energy loss, more nearly resembling viscous damping, which is desirable. Objection might be made that such a pivoting system would permit translation as well as rotation. The objection may be answered in two ways. In the first place the yield of a sheet of rubber to direct compression is very slight. Rubber yields very readily in shear, and this permits rotation. It also yields easily in compression when it can expand freely in a lateral direction, but when a thin sheet of rubber completely fills the space between two surfaces whose dimensions are large compared with the thickness of the

rubber, compression becomes very difficult. In the second place a slight translation would do no appreciable harm, having the effect simply of shifting the center of rotation by a small amount, which does not materially reduce the output. Experience so far with this method of pivoting has shown it very satisfactory.

While the rubber packed journal provides a restoring force, whose magnitude depends on the shape of the post and thickness of the rubber, it is not sufficient to hold the armature in neutral position when a strong magnet is used. It was necessary to provide a supplimentary elastic restoring force in the form of rubber plugs on either side of the "fish tail" or moving end of the armature. The rubber plugs provide not only the needed stiffness or stabilization but a very useful degree of damping.

For the purpose of making a simple analysis of the mechanical properties of the structure we may treat the arrangement as a flexible needle, a rigid rocking beam, with a spring tending to hold the rocker in normal position and an energy absorber in conjunction with the spring. Such a system is illustrated in Fig. 7. A certain motion is assumed to be imparted to the needle

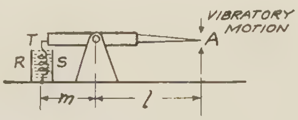


Fig. 7—Reference Figure for Discussion of Mechanical Behavior

tip A, and we are concerned with the motion of the end T of the armature.

Let I = movement of inertia of the armature
- n = stiffness of needle, that is the force at A required to deflect end of needle a given amount, (dynes per centimeter)
- l = distance from pivot to needle point (centimeters)
- m = distance from pivot to end T of armature
- s = stiffness of restoring spring at T (dynes per centimeter)
- R = resistance factor at T, (dynes per unit velocity)
- f = frequency
- ω = $2\pi f$
- A = amplitude of motion at needle tip
- a = instantaneous deflection at the needle tip
- X = amplitude of motion at end T
- x = instantaneous deflection at point T
- θ = angle of deflection of armature from mean direction.

θ is always small so that

$$\frac{x}{m} = \tan\theta = \sin\theta = \theta$$

- P = maximum force applied at A
- p = instantaneous force applied at A.

The driving moment is $p\,l$

The resisting moment is $m\,(s\,m\,\theta) + m\left(R\,m\frac{d\,\theta}{d\,t}\right)$

The difference between these two moments is expended in accelerating the armature

$$I\,\frac{d_2\,\theta}{d\,t^2} = p\,l - s\,m^2\,\theta - R\,m^2\,\frac{d\,\theta}{d\,t} \qquad (1)$$

The problem is most easily solved if we assume a sinusoidal motion at T and find the force and motion at A required to produce it.

Assume $x = X\cos 2\pi f i = X\cos\omega t$ (2)

$$\theta = \frac{x}{m} = \frac{X}{m}\cos\omega t \qquad (3)$$

$$\frac{d\,\theta}{d\,t} = -\,\omega\frac{X}{m}\sin\omega t \qquad (4)$$

$$\frac{d_2\,\theta}{d\,t^2} = -\,\omega^2\frac{X}{m}\cos\omega t \qquad (5)$$

Substituting (3), (4) and (5) in (1) gives

$$-I\,\omega^2\frac{X}{m}\cos\omega t = p\,l - s\,m\,X\cos\omega t + R\,m\,\omega\,X\sin\omega t$$

$$p\,l = X\left(s\,m - I\frac{\omega^2}{m}\right)\cos\omega t - X\,R\,m\,\omega\sin\omega t \qquad (6)$$

$$p = \frac{X}{l}\left\{\left(s\,m - \frac{I\,\omega^2}{m}\right)\cos\omega t - R\,m\,\omega\sin\omega t\right\} \qquad (7)$$

The deflection at the needle tip is the sum of that due to the tipping of the armature and that due to the bending of the needle.

$$a = l\,\theta + \frac{p}{n} \qquad (8)$$

or from (3) and (8)

$$a = \frac{X}{m}\,l\cos\omega t + \frac{p}{n} \qquad (9)$$

$$a = \frac{X}{m}\,l\cos\omega t + \frac{X}{n\,l}\left\{\left(s\,m - \frac{I\,\omega^2}{m}\right)\cos\omega t - R\,m\,\omega\sin\omega t\right\}$$

$$a = X\left\{\left(\frac{l}{m} + \frac{s\,m}{n\,l} - \frac{I\,\omega^2}{n\,l\,m}\right)\cos\omega t - \frac{R\,m\,\omega}{n\,l}\sin\omega t\right\} \qquad (10)$$

Or considering amplitudes only

$$\frac{A}{X} = \sqrt{\left(\frac{l}{m} + \frac{s\,m}{n\,l} - \frac{I\,\omega^2}{n\,l\,m}\right)^2 + \left(\frac{R\,m\,\omega}{n\,l}\right)^2} \tag{11}$$

$$\frac{X}{A} = \frac{1}{\sqrt{\left(\frac{l}{m} + \frac{s\,m}{n\,l} - \frac{I\,\omega^2}{n\,l\,m}\right)^2 + \left(\frac{R\,m\,\omega}{n\,l}\right)^2}} \tag{12}$$

Equation (**12**) shows the manner in which the response will vary with frequency. For uniform response $\frac{X}{A}$ should be constant or independent of ω. As was stated in an earlier paragraph this condition will be realized (1) if the structure is rigid or (2) if the structure is what we might call a spring potentiometer. A rigid structure would mean making the needle stiffness n infinite. This would make equation (**12**) become

$$\frac{X}{A} = \frac{1}{\left(\sqrt{\frac{2}{m}}\right)^2} = \frac{m}{l} \tag{13}$$

or the motions at the two ends are proportional to the lever arm lengths.

Again if the inertia and damping are zero we obtain a constant ratio for $\frac{X}{A}$ for equation (**12**) becomes

$$\frac{X}{A} = \frac{1}{\frac{l}{m} + \frac{s\,m}{n\,l}} \tag{14}$$

in which all the factors are constants.

In equation (**12**) we see that at a certain frequency or value of ω, the factor $\frac{l}{m} + \frac{s}{n\,l} - \frac{I\,\omega^2}{n\,l\,m}$ will become zero. At this frequency $\frac{X}{A}$ will have a maximum value which is limited only by the damping. Setting $\frac{l}{m} - \frac{s}{n\,l} - \frac{I\,\omega^2}{n\,l\,m}$ equal to zero in equation (**12**) gives

$$\frac{X}{A} = \frac{1}{\frac{R\,m\,\omega}{n\,l}} = \frac{n\,l}{R\,m\,\omega} \tag{15}$$

In general damping does not play an important part except near the resonant frequency. The inertia becomes a minor factor when the frequency is well below that at which resonance occurs, so that in the lower part of the frequency range the ratio $\frac{X}{A}$ approximates the constant value shown in equation (**14**). The construction of a reproducer in which distortion is reduced to a negligible quantity, therefore depends on making the resonance occur at a frequency so high that the most important part of the acoustic range is included below the resonance. It is furthermore necessary that there be sufficient damping so that the response at the resonance frequency is not excessive. It is to be noted that the resonance frequency is determined by the inertia of the armature and the restoring force not of the spring or cushions alone, but the combined stiffness of the springs and the needle. The natural frequency of the armature with the needle free has practically nothing to do with the response characteristic of the reproducer. The resonance corresponds to the natural frequency of the armature when the needle tip is held stationary. The action at resonance might be described as a whipping, such that a small movement at the needle tip causes large motion of the armature. Below resonance we may regard the vibrations as entirely forced by the cut in there cord both as to amplitude and frequency.

To obtain a high resonance frequency, the first requisite is to make the moment of inertia of the armature small. At the same time the moving end of the armature must be far enough from the center of rotation to vibrate with considerable amplitude, and from the standpoint of magnetic design the cross-section of the armature must be sufficient to have low reluctance and to avoid any possibility of saturation. In practise it was found that the last mentioned conditions were met when the armature was made heavy enough for mechanical sturdiness and long enough to provide reasonable winding space. Special care has been taken to minimize the mass of those parts of the armature which have greatest motion, metal which is close to the axis of rotation having little influence on the moment of inertia.

The second requisite for high natural frequency is stiffness either in the spring or the needle or both. Reference to equation (**14**) which throughout most of the frequency range is a measure of the response, shows that if we increase the spring stiffness s, we decrease the sensitivity, while increasing n, the needle stiffness increases sensitivity up to a certain limit. It might seem, therefore, that the stiffest needle obtainable should be used, and the spring stiffness should be only what is required to hold the armature in neutral position. But the effect on sensitivity is small so long as the fraction $\frac{s\,m}{n\,l}$ is small compared with $\frac{l}{m}$, and damping is best when a "soft'" needle is used, for the following reason. The needle is a highly resilient spring, whereas the spring S which in the present design consists in a pair of rubber plugs, has a large damping factor. In fact the damping R, and stiffness s, go together. With a given value of s

and R, the stiffer the needle the greater the resonance response, as shown in equation (**15**). Hence we work with the largest ratio of cushion stiffness to needle stiffness which we can use without serious loss of sensitivity. A factor which helps make it possible to get the desired damping without excessive stiffness at s, is the presence of the magnet, which tends to pull the armature away from neutral position and thereby

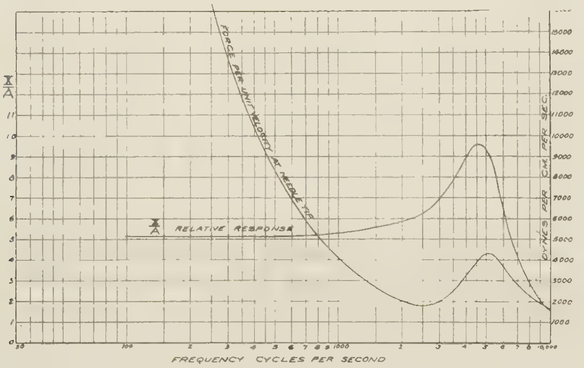


Fig. 8—Calculated Characteristics of Magnetic Reproducer

reduces the net stiffness to considerably less than the value it has when the magnet is removed.

Measurements on a sample magnetic reproducer gave the following values of the principal constants.

Mass of armature with Victor medium needle 1.9 grams.

Moment of inertia of armature and needle $I = 0.28$ gm. cm.^{2}

Length, center of rotation to moving end of armature, $m = 1.1$ cm.

Length, center of rotation to tip of needle (Victor medium) $l = 1.5$ cm.

Stiffness of armature mounting (assumed concentrated at end) $s = 70{,}000{,}000$ dynes per cm.

Same with magnet removed. 90,000,000 dynes per cm.

Stiffness of needle (Victor medium, clamped for ⅜ in.) $n = 86{,}000{,}000$ dynes per cm.

Damping factor as calculated from observed increase in response at resonance, $R = 3720$ dynes per cm. per sec.

Fig. 8 shows characteristics calculated from the above constants. It will be noticed that the required driving force at the needle tip has a minimum value at 2800 cycles. This is the natural frequency of the armature when the needle is free. It is also to be observed that the armature resonance at 5000 cycles is accompanied by an increase in the force reaction. Hence damping to keep down the resonance not only improves the response characteristic, but reduces the wear on the record.

Fig. 9 shows response curves of several factory samples of reproducers, taken by means of an oscillograph. The oscillograph vibrator is supplied from the output stage of a resistance coupled amplifier. The film is run slowly and the width of the envelope of the vibrations is a measure of the voltage applied by the reproducer to the grid of the first tube. The record used for this test is one cut by a special process so as to give an amplitude of cut varying inversely as the frequency. In other words a constant velocity cut is used. The approximate frequencies are indicated on each film. A slight increase in voltage is noticed toward the upper end of the frequency scale, followed by a drop to almost zero, for in all cases the output falls off very rapidly above the resonance frequency.

Scratch Control Circuit. Any exaggeration of the high frequencies produces a disagreeable increase in "surface noise" or "scratch." It has appeared desirable in fact to partially suppress the higher frequencies in order to reduce scratch. This has been accomplished by connecting a coil and condenser in series across the reproducer winding.[7] This shunt circuit tunes at about 4500 cycles but has a decided effect at 3500 cycles and above. The width of the frequency band affected may be controlled by varying the ratio of capacity to inductance, while the degree of suppression for the frequency at which the reactance is minimum, is determined by the resistance of the coil. The suppression of high frequencies is at the cost of some articulation in speech but on the whole gives a more pleasing result, particularly with musical numbers.

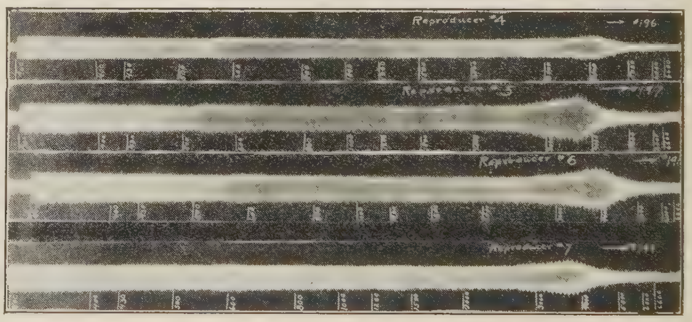


Fig. 9—Relation Between Voltage and Frequency for Magnetic Reproducers

Tone Arm Vibrations. The foregoing analysis of the action of the reproducer is based on the assumption that the device as a whole remains stationary with respect to the axis of the groove in the record. This condition, however, does not necessarily obtain. The net stiffness at the needle tip which is $1/(l^2/m^2\,s + 1/n)$ is sufficient to resonate with the mass of the entire reproducer at a frequency of the order of 150 cycles. Since the reproducer is fairly rigidly mounted on the tone arm, the inertia, flexibility, and

7. The "scratch control" circuit which is being used was a contribution of Mr. Julius Weinberger of the Technical and Test Department of the Radio Corporation of America. He also built the first magnetic reproducer of the bottom-pivoted half rocker type. This model which showed excellent characteristics, served as the basis for the design described in this paper.

mechanical damping in the latter play a part in this type of resonance. Flimsy construction of the tone arm or its mounting gives rise to an irregularity in the response at low frequency, which while not an extreme resonance nor especially noticable in listening is nevertheless a defect. Rigid construction and especially some energy loss at the pivot on which the arm swings, appear to be a practically complete cure for low frequency resonance of the type just described, and with such a satisfactory carriage the response becomes practically uniform from below 100 cycles to above 4000 cycles.

ACKNOWLEDGMENT

The practical success of any device depends in large measure on the engineering skill with which it is placed on a manufacturing basis. In the present case some unusual problems presented themselves and much credit is due Messrs. F. C. Barton and J. E. Albright of the Radio Manufacturing Department, of the General Electric Co., and to Mr. R. Hillner, for the solution of the manufacturing problems and for turning out a final product equal in quality to the original laboratory samples and better in regard to output and reliability. Early experiments by Mr. Barton on magnetic pick-ups showed the possibilities of the system, and interested others in the development.

Acknowledgment should also be made of the important contributions of Mr. Julius Weinberger of the Technical and Test Department of the Radio Corporation of America.[7]

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A. I. E. E. Standards

Annual Report of the Standards Committee[1]

To the Board of Directors:

The Standards Committee has continued actively the revision of the Standards of the Institute, both as to form and content. In 1922, the Institute published its Standards in a volume of nearly 200 pages, divided into 26 chapters, with an appendix in which are reprinted the Rules for Electrical Machinery of the International Electrotechnical Commission. Soon after this edition was issued the Standards Committee was reorganized by the Board, and a revision was begun which involved the splitting up into separate sections the existing Standards, rearranging the material, and bringing together into separate complete compilations, the definitions, service conditions, rating, heating, dielectric tests, markings and other requirements applicable to any particular type of apparatus or brand of the art.

Thirty sections have been definitely projected of which 23 have been issued, 7 are in preparation. Of the 23 issued 2 are reprinted without change from the 1922 edition of the Standards, but one of these sections is now in a revised report form for comment and criticism, and will shortly be issued. Five of the revised Standards have been approved as American Standards by the American Engineering Standards Committee, and other sections are now before that committee for consideration. A complete list of Standards adopted and in preparation is given below as an appendix to this report.

The revised form of the Standards has justified itself in the ease with which revisions may be made in the published sections. The sections are published in comparatively small editions, and revisions are readily made and a new edition printed without much expense

1. Committee on Standards

J. Franklin Meyer, Chairman, Bureau of Standards, Washington, D. C.
H. E. Farrer, Secretary, 33 W. 39th St., New York.

H. A. Kidder,	H. S. Osborne,	C. E. Skinner,
A. M. MacCutcheon,	F. L. Rhodes,	W. I. Slichter,
F. D. Newbury,	L. T. Robinson,	R. H. Tapscott.

Ex Officio

Chairmen of Working Committees.
Chairmen of delegations on other standardizing bodies.
President of U. S. National Committee of I. E. C.

or difficulty. Several of the Standards have been revised in this way. Monthly lists of the Standards available are published in the JOURNAL of the Institute.

The Standards Committee is charged with the coordination of all the standardization activities of the Institute. The Committee has made recommendation to the President and Board of Directors upon all cases of representation of the Institute upon Sectional Committees working in accordance with the procedure of the American Engineering Standards Committee; upon acceptance of and requests for sponsorship by the Institute; and has cooperated very closely with the United States Committee of the International Electrotechnical Commission. The cooperation of the committee with the technical committees is being made closer and more effective. The chairman of each technical committee, or a member of the committee designated by the chairman, is a member of the Standards Committee. Several of the Standards have been formulated by technical committees and accepted by the Standards Committee, and in other cases subcommittees of technical committees have been made the working committee on specific standardization projects.

By direction of the Board, certain Standards have been translated into the Spanish language under the very able supervision of Past President Mailloux. The translation of 19 of the standards has been completed and 13 have been published by the Bureau of Foreign and Domestic Commerce of the U. S. Department of Commerce. By July 1, it is expected that all of the translated sections will be in print. The Spanish edition is printed in the same style and in the same size as the English edition. The translation has been received with interest by engineers in Spanish-speaking countries of South America. The Institute is very much indebted to the Bureau of Foreign and Domestic Commerce for the excellent manner in which the Spanish text has been published, and for the fine cooperation that exists between the Bureau and the Standards Committee. American electrical manufacturers will no doubt find this Spanish edition of considerable value in business relationships in Spanish-speaking countries.

The committee has cooperated to the fullest extent with the American Engineering Standards Committee, the International Electrotechnical Commission and the Standardization activities of other organizations. In the formulation of Institute Standards, the committee has endeavored to enlist the fullest cooperation of all other organizations interested in electrical standardization. Standardization work as now organized in the electrical field, is somewhat complex, and there is of necessity a certain amount of unavoidable overlapping. It is believed, however, that very good progress is being made as represented by the present Standards of the Institute.

Sections of A. I. E. E. Standards

No. 1 General Principles upon which Temperature Limits are Based in the Rating of Electrical Machinery.
5 Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General.
7 Standards for Alternators, Synchronous Motors and Synchronous Machines in General.
*8 Standards for Synchronous Converters.
9 Standards for Induction Motors and Induction Machines in General.
10 Standards for Direct-Current and Alternating-Current Fractional Horse Power Motors.
11 Standards for Railway Motors.
13 Standards for Transformers, Induction Regulators and Reactors.
*14 Standards for Instrument Transformers.
*15 Standards for Industrial Control Apparatus.
16 Standards for Railway Control and Mine Locomotive Control Apparatus.
19 Standards for Oil Circuit Breakers.
22 Standards for Disconnecting and Horn Gap Switches.
30 Standards for Wires and Cables.
33 Standards for Electrical Measuring Instruments.
34 Standards for Telegraphy and Telephony.
36 Standards for Storage Batteries.
*37 Standards for Illumination.
38 Standards for Electric Arc Welding Apparatus.
39 Standards for Electric Resistance Welding Apparatus.
41 Standards for Insulators.
*42 Standard Symbols for Electrical Equipment of Buildings.
*46 Standards for Hard Drawn Aluminum Conductors.

Sections in Preparation

No. 2 Standard Definitions and Symbols.
4 Standards for the Measurement of Test Voltages in Dielectric Tests.
20 Standards for Air Circuit Breakers.
26 Automatic Substations
28 Standards for Lightning Arresters.
45 Recommended Practise for Electrical Installations on Shipboard (Marine Rules).

Now that radio has entered the business of transmitting pictures and messages by the square inch instead of by dots and dashes, it is interesting to note that within its first year of operation the speed of transmission has been doubled. Whereas last year 40 minutes were required for a single photograph of standard size, today it can be done commercially in 20 minutes. Under laboratory conditions the same accomplishment has taken but two minutes.

*Approved by A. E. S. C. as American Standard.

Coupling Capacitors for Carrier Current Applications

BY T. A. E. BELT[1]

Member, A. I. E. E.

Synopsis.—*Coupling to high-voltage transmission lines for purposes of carrier-current communication was first universally made by means of coupling wires. This type of coupling usually required high-power transmitting equipment, but when coupling capacitors were substituted it was possible to reduce the carrier input to the line without affecting the received signal strength. The paper gives an approximate method for determining the effectiveness of coupling wires and coupling capacitors. No attempt is made at refinements in calculations as it is only desired to show the effect of stray capacity. Curves show the change in practise from coupling wires to coupling capacitors. It is estimated that by the early part of 1928 the total number of the two types of coupling will be equal. The electrical characteristics for different types of insulation used in coupling capacitors, based on test results is given. Some important points of design for the new cable capacitor are included.*

* * * * *

Approximate Method for Determining Effectiveness of Coupling

A simple mathematical treatment only is necessary to show the effect of stray capacity. From experimental data it has been determined that the impedance of a single long transmission line to carrier frequencies is of the magnitude of the surge impedance of the line, and that this high-frequency impedance acts as a straight ohmic resistance load. It has also been shown that ground losses are relatively small for interphase coupling. In the following calculations, therefore, the carrier-frequency impedance of the transmission line will be treated as a resistance and the ground resistance will be neglected.

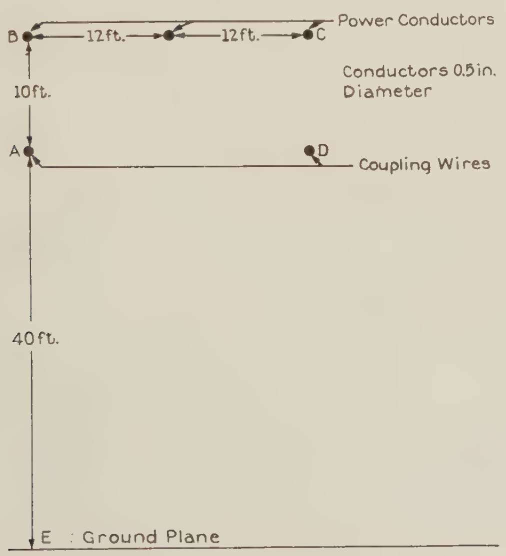

Fig. 1—Diagramatic Illustration of Coupling-Wire Installation

Fig. 1 is a diagramatic representation of a coupling wire installation. It is assumed that the power conductors are horizontally spaced on 12 ft. centers and the two coupling wires are 10 ft. below the two outside power conductors. The ground plane is assumed to be 40 ft. below the coupling wires. For such a coupling-wire installation, the useful capacity between a 1500-ft. coupling wire and the power conductor is approximately the capacity between A B minus the capacity of A C, which is:

$$C_2 = 0.00205 - 0.00027 \ \mu\text{f.}$$

The stray capacities A D and A E between the coupling wires and to ground are of the order of 0.0018 μf. The equivalent circuit of this coupling-wire installation is represented in Fig. 2.

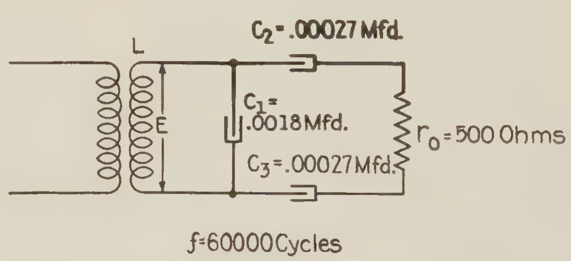

Fig. 2—Equivalent Circuit for Coupling-Wire Installation

Let

f = Carrier frequency
 = 60,000 cycles.

E = Applied carrier-frequency potential
 = 100 volts.

C_1 = Stray capacity between coupling wires and ground
 = 0.0018 μf.
 = 1470 ohms at 60,000 cycles.

C_2 = Effective capacity of one coupling wire to the power conductor.
 = 0.00027 μf.
 = 9800 ohms at 60,000 cycles.

C_3 = C_2
 = 0.00027 μf.
 = 9800 ohms at 60,000 cycles.

r_0 = Equivalent high-frequency resistance of the transmission line.
 = 500 ohms.

Z = Impedance using coupling wires.

1. Engineer, General Electric Co., Schenectady, N. Y.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Calif., Sept. 13-16, 1927.

Z^1 = Impedance using coupling capacitors.

Then for coupling wires (Fig. 2):

$$\dot{Z} = \frac{\dot{Z}_1 \dot{Z}_2}{\dot{Z}_1 + \dot{Z}_2}$$

Where

$$\dot{Z}_1 = o - j\,1470$$

$$\dot{Z}_2 = 500 - j\,(2 \times 9800) = 500 - j\,19600$$

Then

$$\dot{Z} = 67.4 - j\,1360$$

And

$$Z = \sqrt{67.4^2 + 1360^2}$$

$$= 1360 \text{ ohms.}$$

Therefore

$$I = \frac{E}{Z}$$

$$= \frac{100}{1360} = 0.0737 \text{ amperes fed into network}$$

where coupling wires are used.

With properly designed and installed coupling capacitors, the stray capacity effects are very small and vary considerably with each particular installation. By properly arranged circuits, the capacitance between lead-in wires is relatively small. The stray field between units is also small with proper mechanical spacing. Therefore, we will neglect these stray capacities for purposes of calculating the current required using coupling capacitors.

Fig. 3 represents the equivalent circuit for a coupling-

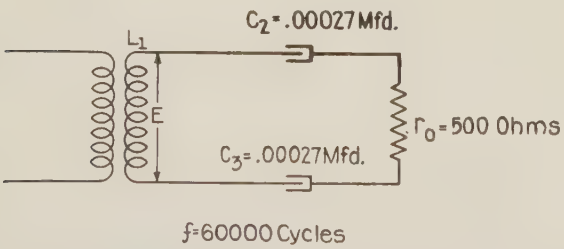

Fig. 3—Equivalent Circuit for Couping-Capacitor Installation

capacitor installation. In order that the calculations may be compared directly with those obtained using coupling wires, the same effective coupling to the power conductor is assumed as before.

Thus for coupling capacitors (Fig. 3):

$$\dot{Z}^1 = 500 - j\,19600$$

$$Z^1 = \sqrt{500^2 + 19600^2}$$

$$= 19600 \text{ ohms.}$$

Hence

$$I^1 = \frac{E}{Z^1}$$

$$= \frac{100}{19600} = 0.0051 \text{ amperes fed into network}$$

where capacitors are used.

We will define the effectiveness of coupling as a per cent ratio:

$$Y = \frac{\text{Useful Current}}{\text{Total Current}} \times 100.$$

Then

$$Y = \frac{0.0051}{0.0737} \times 100$$

$$= 6.92 \text{ per cent for coupling wires.}$$

$$Y^1 = \frac{0.0051}{0.0051} \times 100$$

$$= 100 \text{ per cent for coupling capacitors.}$$

As previously stated, there is a small stray-capacity

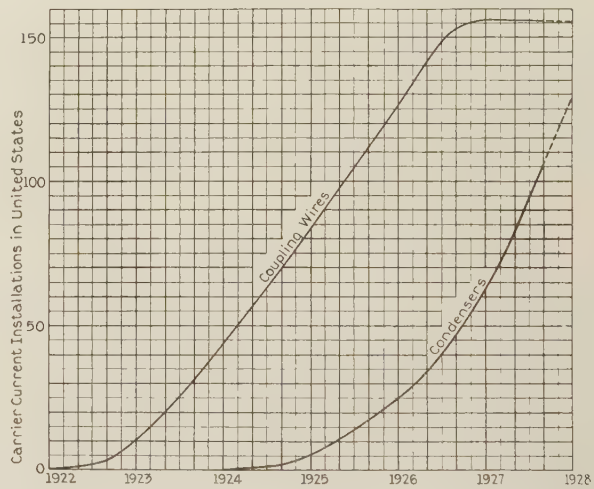

Fig. 4—Curves Showing Number of Carrier-Current Installations, Using Coupling Wires and Coupling Capacitors in the United States

effect when coupling capacitors are used and, therefore, the effective coupling is not actually 100 per cent, but is believed to lie somewhere between 80 and 100 per cent.

Change in Coupling Practise

From the relative effectiveness of coupling wires and coupling capacitors, it is not surprising that the change in practise from coupling wires to capacitors has been rapid. Up to the beginning of the year of 1924 there were no coupling capacitor installations in the United States. Fig. 4 shows the number of carrier-current installations using coupling wires and capacitors. Out of a total of 43 installations at the beginning of the year of 1924, all used coupling wires. At the end of 1924, there were 11 installations using capacitors and 97 using coupling wires. At the close of 1927, it is estimated there will be 130 installations using coupling capacitors and 1 5 installations using coupling

wires; and that in the early part of 1928 there will be as many carrier-current installations using coupling capacitors as those using coupling wires.

Types of Coupling Capacitors

Four distinct types of coupling capacitors are manufactured in the United States:

1. Mica
2. Porcelain
3. Oil Filled Cable
4. Oil Filled Tank

Both the mica and the porcelain type use low-voltage unit construction, that is, the individual units are rated at a definite voltage and capacity. For higher voltage installations series-parallel combinations are used for obtaining the proper voltage and capacitance rating. Some of the characteristics of capacitors, using these different types of dielectrics, are tabulated as follows:

TABULATION OF TEST DATA TAKEN ON 0.001 μf. COUPLING CONDENSERS USING VARIOUS TYPES OF DIELECTRICS

Condenser	Type insulation	Voltage rating	Power-factor per cent at 1000 cycles	Flashover 60 cycles wet r. m. s. volts	Flashover 60 cycles dry r. m. s. volts	Impulse Strength Crest kv.	Impulse ratio
1	Mica	110,000	0.10		585,000	800	0.97
2	Porcelain	132,000	1.670		284,000	300/400	0.75/0.99
3	Oil-filled cable	110,000	0.500	293,000	319,000	800	1.78
4	Tank type (oil and barriers)	110,000	0.500	260,000	355,000	1000/1100	1.99/2.19

On account of lower first cost for medium voltages, the mica and porcelain capacitors have been generally installed on circuits up to and including 66 kv. The oil-filled cable capacitor has a field of application for potentials above 66 kv. The oil-filled tank capacitors are available for 110-kv., 132-kv., and 220-kv. circuits. The 100-kv. and 220-kv. sizes have been in service for a period of approaching two years on several systems throughout the country. Both the Pacific Gas and Electric and Southern California Edison systems are equipped with 220-kv. capacitors.

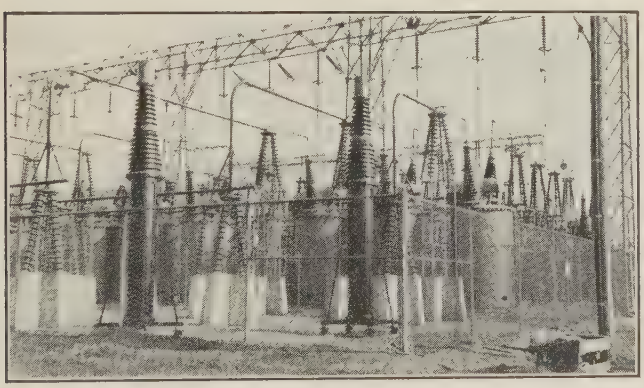

Fig. 5—Tank-Capacitor Installation on Southern California Edison System

Cable Capacitors

The cable and tank[2] capacitors, Fig. 5, are new developments. The cable capacitor, Fig. 6, consists of a short length of paper-insulated oil-filled cable bent into a loop, the free ends of which are stripped of their lead sheaths and brought up through wiping sleeves and electrostatic shields into a porcelain shell, where they terminate in a common terminal. The lead sheath of the cable is attached to the carrier-current output transformer. The whole structure is filled with vacuum-treated oil and hermetically sealed from the atmosphere, so that changing weather conditions do not affect in any way the dielectric strength of the insulation. An expanding metallic reservoir is attached to the capacitor which takes care of the expansion and contraction of the oil caused by temperature changes.

Fig. 6 is a cross-section drawing showing the general details of construction of the cable capacitor for 110,000-volt service.

These capacitors may be mounted on the transmission tower by providing a suitable structural-steel bracket, placed on a base mounting as shown in Fig. 6A, or set up on a framework depending upon the particular requirements of the customer. In the majority of cases the operator will wish to mount the unit outdoor on the steel transmission tower, since the weight of the capacitor—1000-lb.—permits this, and it may be thus placed in a very convenient position at a minimum cost. Connection to the line is then simple and direct; the unit is far enough up so that no surrounding fence is

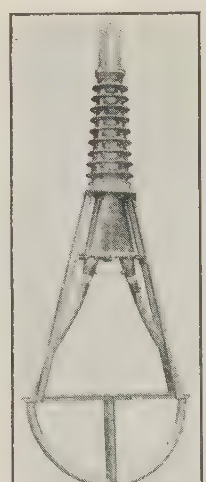

Fig. 6—Cable Couping Capacitor for 110-Kv. Transmission System

2. For purposes of brevity it has been necessary to omit the description of the tank capacitor but it is planned to present a paper on this type of capacitor at a later date.

required to protect against marauders, and periodic examination is not handicapped.

The voltage of cable-type capacitors is limited only by the voltage rating of available cable. At the present writing, the highest voltage commercial cable is 132 kv., but 154-kv. cable is now being built for capacitors of this rating, and specifications on 220-kv. cable for a proposed 220-kv. cable-type capacitor have been prepared. For the time being, it is not contemplated that the cable-type capacitor will be developed for voltages below 66 kv. because at the lower voltages the cost is higher than for some other types of capacitors.

The porcelains used on these units are similar to those used for standard oil-filled bushings for power apparatus; so that uniformity of practise in this respect is preserved.

At first glance it might appear that cable capacitors

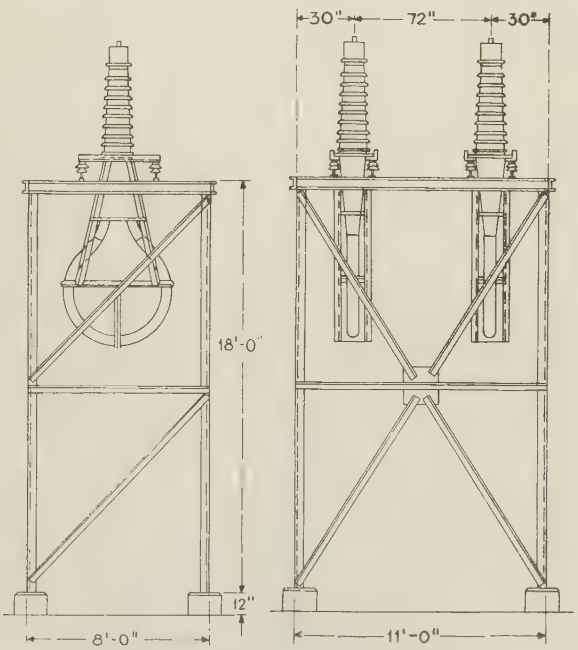

Fig. 6a—Framework Mounting for Cable Capacitors

have considerable inductance due to the loop of cable, but a little thought shows that there is no external magnetic field if connection to the lead sheath is made at the top, for then at every cross-section of the cable the current in sheath and conductor is of the same magnitude, and the magnetic flux is therefore confined to the space between conductor and sheath. On the assumption of a linear distribution of current from the terminal to the low point of the cable loop where the current is zero, (for reasons of symmetry), the total stored magnetic energy corresponds to an equivalent inductance equal to only 1/12th that between the conductor and sheath of the active length of cable employed. This is about 5×10^{-9} henry per ft.

The specially treated paper used in the construction of this cable gives it a capacitance of about 73.2×10^{-6} μf. per ft. Therefore less than 14 ft. of cable has

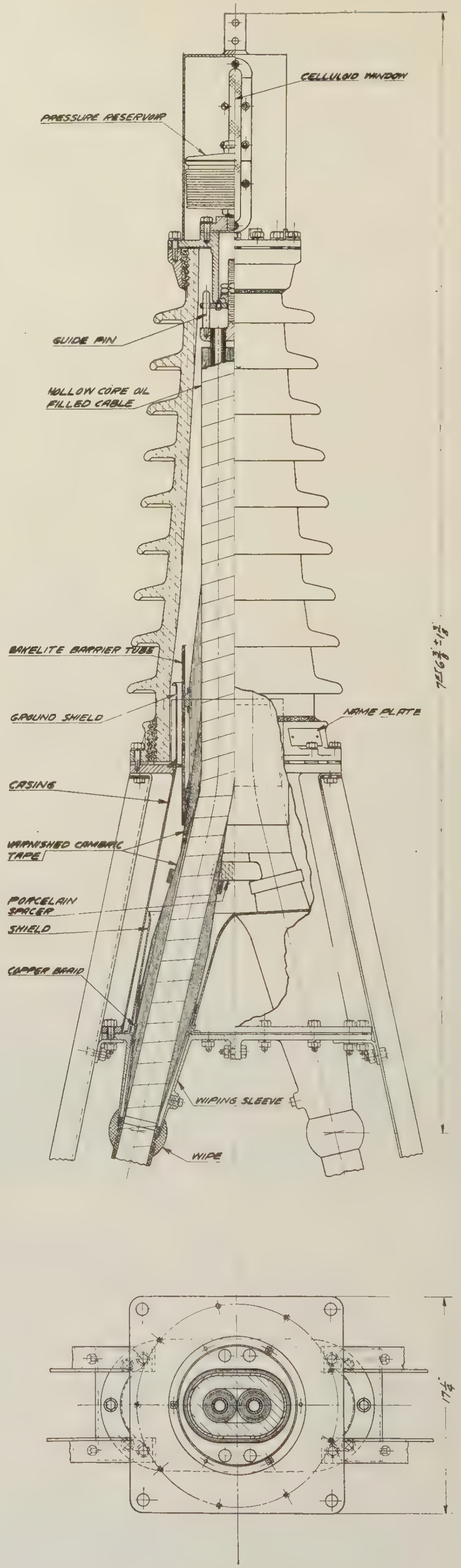

Fig. 7—Cross-Section of Cable Capacitor

the required capacitance of 0.001 μ f. for coupling purposes. From 75 per cent to 85 per cent of the total capacitance is in the external loop of cable for the 0.001 μ f. units.

In the manufacture of cable capacitors it is important that the bending of the cable be done without wrinkling the paper dielectric. For this reason bending forms are used for shaping the cable loop. The transition from the several lead sheaths of the cable is effected by applying (on a taper) varnished cambric tape overlaid with copper braid until a diameter is reached

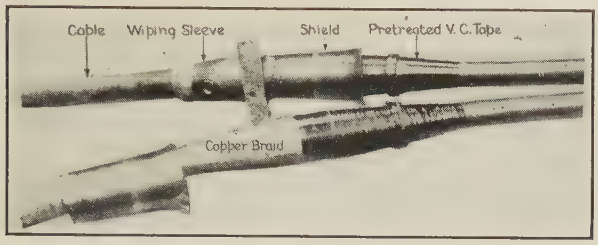

Fig. 8—Internal Construction of Cable Capacitor

at which a layer of oil may be introduced without exceeding the allowable radial gradient for oil, see Fig. 8. At this diameter a smoothly flared conical shield continues the metal surface until it intersects the wall of the casing. The function of this shield is to increase the thickness of the oil layer at such a gradual rate that excessive longitudinal stresses are avoided. When the flare of the shields has opened out to a sufficient diameter, the varnished cambric is again tapered down to the surface of the cable paper. A small porcelain spacer is inserted to preserve the proper spacing and then a double wrapping of varnished cambric tape applied to serve both as a mechanical binder and to relieve the radial stress on the oil, which increases as the ground shield inside the bushing shell is approached.

The sheet-iron casing is oval shaped at the bottom where it bolts to the wiping sleeves, and then gradually changes to a circle at the top where it meets the bushing shell. The shape and dimensions of this casing have considerable influence on the design. The slope of its walls must not differ enough from the slope of the insulation as to cause excessive longitudinal gradients, and must have sufficient clearance to prevent excessive circumferential stresses.

It is important that there always be a positive oil pressure inside the capacitor, so that no air or moisture can enter. For this purpose a pressure reservoir, actuated by an internal mechanism, keeps the oil under a pressure *above* that of the atmosphere. The reservoir is filled at the factory in such a manner as to compensate for the yearly temperature variation at its destination.

On the end castings of the pressure reservoirs there are four small radially projecting guides, which center the reservoir inside its sheet-iron cover. This cover has two celluloid windows through which the position of the reservoir may be observed. A terminal is welded to the top of the reservoir cover, for connection to the transmission line.

Vacuum Treatment and Oil Filling

In a piece of apparatus of this kind intended for satisfactory operation over an indefinite period of time without attention, except for an occasional inspection, it is of primary importance that its interior insulation be absolutely free from moisture and air. For this reason, hermetically sealed cable capacitors are subjected to a very elaborate and efficient system of factory inspection and vacuum treatment. The bushing shell, casing, and pressure reservoir are individually tested with oil under pressure. During assembly every precaution is taken to keep the internal parts clean and free from moisture or foreign material.

When the capacitor has been assembled, a connection

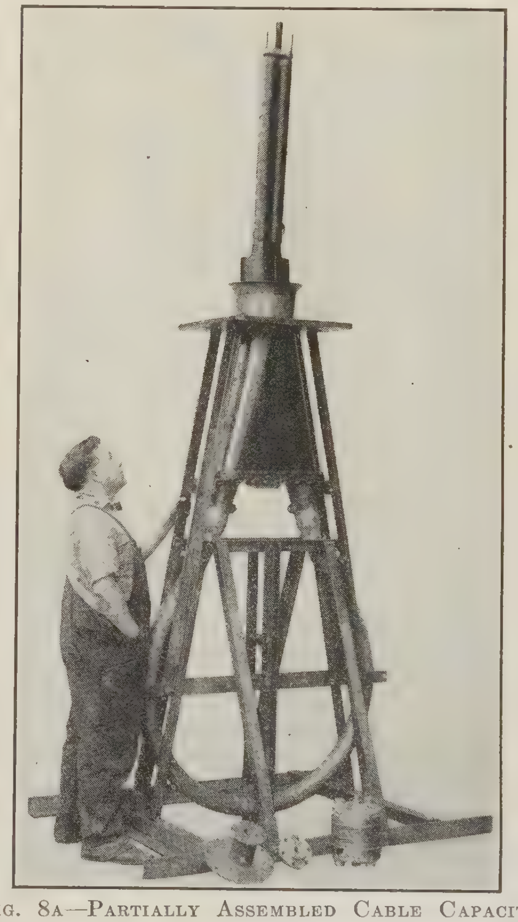

Fig. 8a—Partially Assembled Cable Capacitor

to a vacuum pump is made at the top of the bushing, with the pressure reservoir removed. A vacuum of 200 to 500 microns[3] absolute pressure is maintained during the treatment, at the end of which the capacitor is ready for filling with No. 10-C transil oil at 120 deg. cent. which has been kept at that temperature and under vacuum for 20 hours previous to the filling of the capacitor. This oil must test 30 kv. or better between one inch diameter disks spaced 0.1 in. apart.

During the entire vacuum treatment the temperature

3. There are 25,000 microns per inch of mercury.

of the cable is maintained at 100 deg. cent. on the outer lead sheath and at about 140 deg. cent. on the conductor by circulating currents in the cable as the secondary of a transformer.

The filled capacitors are allowed to cool for several hours under a pressure head of 5 lb. per sq. in. After cooling, they are disconnected from the oil and vacuum system and hermetically sealed with their pressure reservoirs. Before sealing, the reservoirs are expanded by oil pressure to the necessary height.

Marine Work

Annual Report of Committee on Applications to Marine Work*

To the Board of Directors:

The committee in making its report this year does so with a feeling that its efforts to raise the standards of marine electrical installations and increase the utilization of this most efficient, flexible, and safe form of energy, appear more assured than at any time before.

The untiring efforts of the committee as a whole, and individually of the members, with the section of the industry they represent, have, by the dissemination of information, removed to a large extent the opposition and indifference to electric drives, which has been due to a lack of information, and experience in the past, on the part of the owners and operators.

An equally deciding factor, and one for which the committee hereby desires to acknowledge its appreciation, has been the recognition accorded by various bodies covering inspection, classification, and insurance; *viz.*, United States Government Departments, American Bureau of Shipping, National Board of Fire Underwriters, National Fire Protection Association, and similar associations, thus establishing complete harmony in the endeavor to increase the usefulness of electricity, surrounded by the necessary safeguards.

Electric drive is not only gaining headway in its application to deck machinery, engine room auxiliaries, and cargo pumps, but also as a means of propulsion for tugboats, ferryboats, and all classes of vessels where frequent starting and stopping is necessary, and where large torques are required at minimum speeds. This headway has been due to a careful study of the particular application by the designing and operating engineers and to the hearty cooperation of the electrical manufacturers to build special apparatus, where standards were not the most suitable and advantageous, and there is every evidence of a continuance of this spirit.

It will be recalled that in 1920, the Institute issued a volume, *Recommended Practise for Electrical Installations on Shipboard*, which was accepted and used by a great majority of the naval architects, marine engineers, ship owners and shipbuilders, and recognized by the Insurance and Classification Societies as having filled a long-felt want. The committee takes pleasure in announcing that after three years of close application to the study of revision, the Institute will at an early date issue the revised edition which represents the combined efforts of representatives from United States Navy Department, Classification and Insurance Societies, electrical manufacturers and shipbuilders, for which sincere appreciation, by the Institute and the committee, is hereby acknowledged.

Arrangements are being made to give this edition wide circulation; first, that it may add to the simplification and standardization movement which is being so urgently advocated by the United States Government Department of Commerce, and secondly, that the Institute's standards may be universally adopted, which ultimately will result in better products of uniform manufacture at lower first costs and maintenance.

The economic feature of shipbuilding is at a low ebb and has not materially changed since the war; furthermore, there is little hope of any relief until some changes are made in our shipping laws.

Shipbuilders and owners of the United States cannot hope to compete with those of any other country, owing to material and labor prices. Our shipping laws provide protection only in the coastwise trade, and necessarily the advantages of electric drives which originated, and have been highly developed, in this country, have opportunity for demonstration only in that class of vessels.

G. A. Pierce, *Chairman.*

*Committee on Applications to Marine Work:

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	H. M. Southgate,	

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Electric furnaces which are great tubes sunk in the ground are used to heat ship's guns in order to expand them to take new barrel linings. In the giant 16-inch guns these linings have to be replaced after each 100 discharges of shells using explosives of war strength. They will endure about 300 shots in peace-time target practice. The guns are lowered into and withdrawn from the furances by electric cranes.

Abridgment of

Non-Harmonic Alternating Currents

BY FREDERICK BEDELL[1]

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Synopsis.—*Certain principles are presented for solving non-harmonic a-c. problems. Graphical methods are already well known for solving practically any problem, when currents and electromotive forces are sinusoidal, by vector diagrams in a plane. In certain special cases such diagrams give correct results when currents and electromotive forces are non-sinusoidal, but in general diagrams in more than two dimensions are necessary. A wide range of material, some of which has been published before in scattered places, is brought into relation; no single general solution seems attainable. A Bibliography with 61 references is appended.*

Scope and Limitations of Usual Sine-Wave Assumption. It is common, in discussing the theory of alternating currents, to assume that currents and electromotive forces are simple harmonic functions of the time; that is, they are plotted as sine waves. It has been found that, for most purposes such a wave is superior to a wave that is irregular or complex, which, to distinguish it from a simple harmonic wave, may be referred to as non-sine, or non-harmonic. The technique of alternator design has been highly developed with a view to attaining a sine wave of electromotive force as closely as possible, the subject being fully discussed in many texts and special articles, Bibliography, 33. Methods have been developed for measuring and penalizing departure from a sine wave and much study has been given to the specification of allowable limits to such departure, Bibliography, 9, 43, 44, 46, 47, 58, 61.

On the sine-wave assumption there has been developed a very complete analytical theory of alternating currents and, in parallel with it, a graphical method of representation and analysis that gives ready and accurate solution to practically any problem that arises. It has been found that harmonically varying quantities can be represented as vectors in a plane, and that these vectors, by showing the phase and amplitude of the several harmonic quantities, completely define them. Furthermore, any vector may be resolved into components and, conversely, two or more vectors may be added or combined, as in the polygon of forces. Thus, a current may be resolved into two components at right angles to each other, one a power component in phase with electromotive force and the other a reactive component in quadrature thereto. Similarly, an electromotive force vector may be resolved into its power component in phase with current and a reactive component in quadrature, Bibliography, 11.

Apparent power is the product of the electromotive force E and the current I, but real power is the product of E, I and a power factor, $\cos\theta$, where θ is the angle of phase difference between E and I. Real power may, accordingly, be looked upon either as the product of the electromotive force and the power component of current or as the product of the current and the power component of electromotive force. The product $E\,I \sin\theta$ is a pulsating reactive power with average value zero, where $\sin\theta$ is the reactive factor and $I\sin\theta$ is the reactive component of current; $E\sin\theta$ is the reactive component of electromotive force.

There is scarcely a circuit problem that cannot be solved by methods based upon these principles; the whole treatment, however, is based upon the sine-wave assumption.

An exact sine wave, however, is practically never obtained from commercial apparatus. In practise, currents and electromotive forces deviate to a greater or less extent from a simple sine function of the time. It is true that in many cases, though there be this deviation from a sine wave, conclusions based on a sine-wave assumption are sufficiently accurate for practical purposes; indeed, in certain cases, conclusions thus obtained are strictly correct and the results are the same irrespective of whether we are dealing with sine or non-sine waves. In other cases, however, deviation from a sine wave causes error in results obtained on a sine-wave assumption, and this error may be large or small according to the conditions of the problem. A careful study of non-harmonic alternating currents, therefore, is desirable.

Complex Wave Represented by Fourier's Series. Any periodically varying quantity, such as we are here discussing, can be completely represented by a constant term and a series of sine terms, of definite amplitude, phase and frequency. Cosine terms are unnecessary when the phase of each sine term is included. The series of sine terms used to represent an irregular a-c. wave includes a *fundamental,* or sine wave of fundamental frequency, and various *harmonics* with frequencies that are odd or even multiples of the fundamental frequency; a constant term is added in the general case. The introduction of factors of exponential form, that occur in transients and in cases of damping, will not be considered here, Bibliography, 30.

For Usual Alternating Currents, Positive and Negative Areas are Equal and the Constant Term is Zero. The average value of any complex wave, expressed as in the

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preceding paragraph, is the constant term, the average value of the fundamental and the various harmonics, taking account of sign, being zero. The average value must be taken over a complete period. In an ordinary alternating current, with no predominating flow in one direction, the average value or constant term is zero; and, since the average of the positive ordinates is equal to the average of the negative, the areas of positive and negative half-waves are equal. Inequality of areas indicates a direct current combined with the alternating and this direct current would be represented by the constant term. This is a case that sometimes occurs.

In a generated electromotive force wave, the equality of positive and negative areas indicates that the total flux cut in a positive sense is equal to the total flux cut in a negative sense, as is the case in any dynamo-electric machine. It is seen, therefore, that in the wave for electromotive force, as well as in the wave for current, the constant term is zero.

When positive and negative half-waves are alike, odd harmonics only can be present.

Average Product Theorem. The average product of the instantaneous values of two harmonic quantities of different frequencies is zero. This is true irrespective of their relative phase positions and the ratio of their frequencies; the same is true of the product of any periodic quantities, each of which is represented by a series of harmonic terms.

This may be illustrated experimentally by passing currents of different frequencies through the two coils of a wattmeter and noting that the reading is zero. Formally, it may be shown by integration of the product of two sine functions, having different periods, over the least common multiple of the two periods; or, over the longer period when one period is a multiple of the other. In case the two periods were nearly equal and their least common multiple very large, beats would occur, but the average value of the product over a sufficiently long time would still be zero, Bibliography, 13, 14 (p. 391).

The average value of a constant, multiplied by a sine function, or by the sum of several sine functions, is likewise zero.

The results of these relations are far reaching; root-mean-square values and average power for non-harmonic waves both depend upon this average product theorem.

Root-mean-square Value of Non-harmonic Wave. A non-harmonic wave, as already explained, consists of a series of harmonic components of fundamental and higher frequencies. It will be shown that the r. m. s. value of the total wave is equal to the square root of the sum of the squares of the separate harmonic components. Thus, if the fundamental is A, and the several harmonics B, C and D (r. m. s. values), the r. m. s. value of the total wave is $\sqrt{A^2 + B^2 + C^2 + D^2}$. This will be referred to later as the *square law.* It will be seen that the result is *independent of the phase and frequency* of the several components. The effect of each component is added as though it were in quadrature to each other component, Bibliography, 13, 14.

This may be demonstrated experimentally by taking voltmeter readings of the separate and total voltages when two or more electromotive forces, not of the same frequency, are connected in series; or, more laboriously, by plotting curves for the instantaneous values of the components and determining r. m. s. values of their sum.

If, collectively, the harmonics B, C and D are represented by H, where $H^2 = B^2 + C^2 + D^2$, the r. m. s. of the total wave is $\sqrt{F^2 + H^2}$, where F is the fundamental. It is seen that the collective harmonics add as a component in quadrature to the fundamental.

The proof of the foregoing is readily seen. The non-harmonic wave may be represented by a series of sine terms of different frequencies. One of these terms may be a constant, representing a d-c. component, if desired. When this series is squared, to get the r. m. s. value, every term is multiplied by itself (so that any term, as A, becomes A^2) and by every other term. But the cross-products, obtained by multiplying together terms of different frequencies, all vanish, for their average product, by a theorem already stated, is zero. The only terms remaining are the square terms, as A^2, B^2, etc., the r. m. s. value of which is $\sqrt{A^2 + B^2 + C^2 + D^2}$.

One of the terms in the preceding expression may be a constant, representing a d-c. component. It is thus seen that a direct current, when superimposed on an alternating current, adds vectorially in quadrature, in the same manner as an alternating current of a different frequency; the resultant is the square root of the sum of the squares of the component currents.

Principles of Independent Superposition of Harmonic Alternating Currents of Different Frequencies. When a pure sine electromotive force is impressed upon a circuit in which the various resistances, inductances and capacities are constant, the current that flows is a pure sine wave of the same frequency, with amplitude and phase dependent upon the constants of the circuit.

When the electromotive force wave contains not only the fundamental sine wave, but harmonics as well, the current will contain a fundamental and harmonics of these same frequencies. Furthermore, each harmonic component of the electromotive force will produce in the current a corresponding harmonic component of the same frequency, *exactly as though all other components were absent,* Bibliography, 6, Chap. XI.

This holds true of any part of a complex circuit, as well as of the circuit as a whole. Thus, if the harmonic components of the electromotive force, either in the whole circuit or in a part, are E_1, E_3, E_5, the corresponding components of current are I_1, I_3, I_5, each component being determined independently as though it alone existed.

By the square law, the sum of the component electromotive forces is

$$E = \sqrt{E_1^2 + E_3^2 + E_5^2}.$$

The sum of the component currents is

$$I = \sqrt{I_1^2 + I_3^2 + I_5^2}.$$

The phase of each harmonic component, as well as its amplitude, is determined independently. Although these phase relations affect the wave-shape, they do not affect the r. m. s. value of the total current.

When a circuit contains a constant resistance only, the harmonics in the current wave will have the same relative amplitude and phase positions as the several harmonics in the electromotive force wave; that is, the current and electromotive force are similar in wave-form. With reactance present, however, this will not be true, for the relative amplitudes and phase positions of the several harmonics in the current will vary with their several frequencies.

In the case of inductive reactance, the reactance of the circuit for the several harmonics increases in proportion to frequency, thus increasing the lag and decreasing the amplitude of the corresponding harmonics in the current wave. Inductance tends to choke out the higher harmonics and to make a smoother current curve. Capacity reactance, on the other hand, amplifies harmonics in the current and so increases, rather than smooths out, irregularities in its wave-form. With either inductive or capacity reactance present, the wave-forms of current and electromotive force, except in the case of pure sine waves, are no longer similar. The resultant wave-form of current, however, is built up from its separate harmonic components, for the principle of independent superposition holds, so long as resistance, inductance and capacity are constant. When one function, as current, is related to another, as electromotive force, by a linear differential equation in which the coefficients are constant, as a matter of course, one function may be derived from the other by a so called "distributive" operation, and the principle of independent superposition holds.

Should resistance, inductance or capacity be variable, the principle of independent superposition cannot be applied. In this case, as discussed later, a sine-wave electromotive force does not produce a sine-wave current; the separate harmonic components of a complex electromotive force, therefore, do not produce corresponding independent components in the current.

When a Current Comprises Components of Different Frequencies, Each Component has Its Independent Resistance Loss; the Total Resistance Loss, $R\,I^2$, is the Sum of the Losses due to the Separate Components. As already shown, when a current I comprises components I_a, I_b, I_c, etc., of different frequencies, the r. m. s. value of the total current is the square root of the sum of the squares of the separate components;

$$I = \sqrt{I_a^2 + I_b^2 + I_c^2 + \ldots}$$

Hence,

$$R\,I^2 = R\,I_a^2 + R\,I_b^2 + R\,I_c^2 + \ldots$$

Each component has its own resistance loss as though it alone existed; the total loss is merely the sum of these separate losses. This is equally true when one component is direct current.

As an illustration, if two unlike currents, either direct and alternating, or alternating currents of different frequencies, of 10 amperes each, are superposed in a circuit having a resistance of one ohm, the total loss is 200 watts, the separate losses being 100 watts each. This is an interesting contrast with the case when two *like* currents, two direct currents, or alternating currents of same phase and frequency, of 10 amperes each, are superposed in the same circuit having resistance of one ohm; the total loss in this case is 400 watts, although the loss would be only 100 watts for either current flowing alone. (For references, see next paragraph).

Copper Saving in Composite Systems of Power Transmission. It is obvious from the foregoing that a considerable copper economy could be effected were it possible to use the same lines for the simultaneous transmission of power by unlike currents, that is, by direct and alternating currents or by alternating currents having different frequencies.

Inasmuch as copper drop is proportional to copper loss, each current in such a composite system would have its own independent copper drop as well as copper loss; and, where the amount of copper is determined by allowable copper drop or loss, no more copper would be required to carry several currents for composite transmission than would be required to carry one current alone. The independence of copper drop is very striking. Thus, if two generators transmit unlike currents over the same lines to independent loads, one for lighting and the other for power, the regulation of the lighting load is in no way affected by most extreme variations in the power load; for example, an entire power load with line drop of, say, 50 per cent could be thrown off and on without producing even a flicker in the lamps constituting the lighting load. These results are confirmed by test.

Although several composite systems have been proposed, the complications involved have thus far prevented their general adoption, Bibliography 16, 17, 19, 20, 21, 22.

Equivalent Sine Wave. Although a non-harmonic alternating quantity requires a series of harmonic terms for its complete representation, it can be represented, for many purposes, by a single sine wave having the same r. m. s. value and the same frequency. Such a wave is called an *equivalent* sine wave. It is equivalent, however, in a restricted sense only. Thus, inductance and capacitance can completely neutralize each other in case of true sine waves only, complete neutralization being impossible for non-sine waves or for their equivalent sine waves.

If a non-sine wave is plotted in polar coordinates, the equivalent sine wave is plotted as a circle with the same area. If a non-sine wave and its equivalent sine wave are plotted in rectangular coordinates, the curves formed by the squares of their ordinates enclose equal areas, thus giving equal mean-square and r. m. s. values.

Vector Representation of Equivalent Sine Wave. A non-harmonic alternating quantity can be represented by a vector corresponding to its equivalent sine wave. There seems to be no criterion, however, for satisfactorily defining the absolute phase location of an equivalent sine wave with respect to the irregular wave to which it is equivalent, although the phase displacement of one equivalent sine wave with respect to another, as a current with respect to an electromotive force, can be determined. As discussed later, this phase relation is, in general, definite between pairs of quantities only. Accordingly, except in special cases, only two equivalent sine waves can be represented as vectors in a plane and three such waves as vectors in space, if all their phase relations, as well as magnitudes, are to be correct. More vectors would require more dimensions, or would necessitate a lack of significance in the relative phase positions of some of the vectors. The sum of two equivalent sine waves can be vectorilly represented, however, in the same plane as the two waves themselves, and the sum of three equivalent sine waves can be represented with them in space, as discussed later.

Equivalent Phase Difference. The equivalent phase difference between two non-sine waves of the same frequency is the phase difference between the two equivalent sine waves when so located with respect to each other that the mean product of their instantaneous values is the same as the mean product of the instantaneous values of the two non-sine waves of which they are the equivalent. In the case of a current and an electromotive force, this mean product is the average power, the equivalent phase difference being an angle whose cosine is equal to the power factor.

Lag or Lead of Non-Sinusoidal Current. In case of sine waves of current and electromotive force, inspection of the waves plotted with respect to time shows at once whether the current is lagging or leading in relation to the electromotive force. If the current is lagging, the current passes through zero and attains successive values, as ¼, ½, ¾ and full maximum value, a certain interval of time, depending upon the constants of the circuit, after the electromotive force attains its corresponding value. This time interval or lag is the same between zero as between maximum values of current and electromotive force and is a measure of the phase difference. Power and power factor are increased when a lagging current is advanced, or when a leading current is retarded, in phase.

In case of non-sine waves, however, these definite relations do not hold. Except in special cases, the time-lag measured between zero points of current and electromotive force is different from the time-lag measured between maximum values, and in neither case does its value correspond to the equivalent phase difference. Indeed, the current might lag behind the electromotive force in reaching its maximum value and be in advance of it in passing through zero, so that inspection does not show whether the current is lagging or leading, nor whether the angle of equivalent phase difference is negative or positive. This uncertainty, however, does not affect the numerical value of the power factor, for the cosine of an angle is independent of its sign.

Arbitrarily, a current is said to lag when its maximum value occurs later than the maximum value of the electromotive force, Bibliography, 61; but the time of passing through zero has also been used as a criterion, Bibliography, 26. Although not used, a better criterion might depend upon power. Thus, current would be referred to as lagging when an increase in power and power factor is brought about by advancing it in phase, and as leading when increase in power and power factor is brought about by retarding it. This is discussed later under power factor.

Two Equivalent Sine Waves of the Same Frequency, and their Sum or Difference, can be Represented by Vectors in a Plane. Three vectors, 1, 2 and 3, representing non-harmonic quantities of the same frequency, do not in general lie in a plane. Thus, if the equivalent phase difference between 1 and 2 is 40 deg., and between 2 and 3 is 10 deg., the equivalent phase difference between 1 and 3 may be neither 30 deg. nor 50 deg. The representation of three non-harmonic quantities by vectors in a plane is correct, however, when one of the quantities is the sum or difference of the other two; that is, the vectors in this case correctly show the relative phase differences between the three quantities, as well as their magnitudes. Thus, let A and B be the r. m. s. values of two non-harmonic quantities and C the sum. If three vectors are drawn in a plane so that C is the vector sum of A and B, it will be found that the angle between any two vectors will be their equivalent phase difference, as already defined; if one vector represents an electromotive force and the other a current, the cosine of this angle gives the true power factor. Or, if two vectors A and B are drawn with an angle between them equal to their equivalent phase difference, their vector sum will give the r. m. s. value of the sum of the two non-harmonic quantities that they represent, Bibliography, 13, 14 p. 391, 15, 39.

Again, if a is the equivalent phase difference between two non-harmonic quantities and if b is the phase difference between them when one of the quantities is reversed, the sum of the angles a and b is 180 deg.; the vector representing one of the quantities is reversed, as though the quantities represented by the vectors were harmonic.

The correctness of vector addition and subtraction of non-harmonic quantities may be rigorously proved, or

may be verified either by experiment or graphical construction, Bibliography, 13, 14.

The once famous three-voltmeter and three-ammeter methods are illustrations of the general theorem that vectors in a plane may represent two non-harmonic waves and their sum. In the three-voltmeter method, three voltmeter readings are drawn as vectors in a plane; E_1 measured across a load; E_2 measured across a non-inductive resistance in series with the load; and E, their sum, measured across the two. In this case, not only the three voltages but also the current I can be represented[4] as vectors in a plane, for $I = E_2 \div R$, where R is constant, and any representation of I is the same as the representation of E_2 with the scale changed. The equivalent phase difference between E_1 and I in the load is thus determined, giving power factor $\cos \theta$, and power. In the three-ammeter method there is a similar relationship, vectors in a plane being drawn to represent the electromotive force E as well as the currents, I_1 in a load, I_2 in a non-inductive parallel circuit, and I, their sum. The three-voltmeter and three-ammeter methods may be considered as proved by the general theorem; or, they may be considered as a proof of the theorem for these special cases, Bibliography, 2, 7.

Otherwise stated, we may represent as vectors in a plane the various currents and voltages in a system consisting of one unknown load circuit of any character and a single pure resistance, either in series or in parallel with it. By extension, see preceding footnote, we may include in the system any number of pure resistances connected in any way whatsoever with the one unknown circuit; thus, some of the resistances may be in series and some may be in parallel with it, provided in each one there is a linear relation, $e = R\,i$, between current and electromotive force. In the one unknown load circuit, however, there need be no simple relation between e and i; the current in it may be distorted, as by hysteresis, and have a very different wave-form from the electromotive force. A single voltage and a single current in the unknown load circuit are included in the vector representation in a plane. If the voltage or current in the unknown circuit is split up into parts or components, such parts or components cannot be represented in the plane.

Three Equivalent Sine Waves of the Same Frequency, and their Sum, can be Represented by Vectors in Space. In a like manner three non-harmonic alternating quantities, together with their sum, can be represented as vectors in space, the length of the vectors being equal to the r. m. s. values of the various quantities and the angle between any two vectors being equal to their equivalent phase difference. More quantities can be so represented only when they are linear functions of those already represented; thus, if three currents are represented in space, any voltage drops proportional thereto may also be represented. This follows as an extension of the preceding case, Bibliography, 16, 18 to 23, 25, 29 pp. 217-9, 34, 42, 45, 53.

More than three vectors representing non-harmonic quantities cannot, in general, be drawn in space; but the resultant of two of these can be used, together with the other two, to construct a three-dimensional figure. In the same way, three vectors cannot, in general, be drawn in a plane; but the resultant of two of these can be drawn with the third in a plane. The three resultants of any number of quantities can thus be represented in space, or two resultants in a plane, Bibliography, 34, but this is a cumbersome procedure of doubtful utility.

Variation of resistance, inductance or capacitance causes wave distortion.

Pyramidal Space Diagram. The three star voltages of a three-phase system, which lie in a plane when there is no wave distortion, have the neutral point raised from the plane by the third harmonic voltage and its multiples, so that the three star voltages become the edges of a pyramid. Similarly, a diagram with vectors in space is required for representing line and delta currents, when harmonic currents circulate in the delta without appearing in the line, Bibliography, 29, pp. 217-9.

T-connected transformers produce dissimilar wave forms.

Power. When alternating currents and electromotive forces are complex, containing components of fundamental and higher frequencies, each component has its own independent power and power factor. The total power is the sum of the power of the separate components; thus, the total average power is

$$E\,I \cos \theta = E_1 I_1 \cos \theta_1 + E_3 I_3 \cos \theta_3 + \ . \ . \ .$$

The independence of the average power of the separate harmonic components results from the fact, already pointed out, that the average product of harmonic components of different frequencies is zero, so that, when complex currents and electromotive forces are multiplied together, only products of currents and electromotive forces of the same frequency remain. This relation is always true, irrespective of the nature or the amount of distortion in the electromotive force or current wave.

Apparent power is not, in general, the sum of the separate apparent powers. *The instantaneous power* for each component is a quantity of double frequency varying harmonically about its average value, Bibliography, 36.

Power Factor. From the foregoing, it follows that power factor, in case of a complex wave, is

$$\cos \theta = (E_1 I_1 \cos \theta_1 + E_3 I_3 \cos \theta_3 + \ . \ . \ . \ ) \div E\,I,$$

θ being the equivalent phase difference between the complex E and I.

It will be seen that in determining the combined

4. More generally stated: Where certain quantities are represented as vectors in a plane, any other quantities that are linear functions of these may likewise be so represented, Bibliography, 15, 23. When $e = R\,i$, e is a linear function of i. When $e = R_1 i_1 + R_1 i_3$, e is a linear function of i_1 and i_2.

power factor, $\cos\theta$, the power factor of each component is given a weight in proportion to the ratio of the apparent power of the component to the total apparent power. There is, however, no simple general relation between the combined power factor and the power factor of the separate components.

A circuit with reactance increasing and power factor decreasing with frequency, as R and L in series or R and C in parallel, will have a lower power factor with an irregular electromotive force wave than with a sine wave. On the other hand, a circuit with reactance decreasing and power factor increasing with frequency, as R and C in series or R and L in parallel, will have a higher power factor. It is thus seen that harmonics in an electromotive force wave may decrease or increase power factor according to the character of the circuit.

Any change in the relative amplitudes of the separate components of electromotive force and corresponding components of current changes the total power factor and at the same time changes wave form. Any change in their relative phase positions, however, while changing wave form, has no effect on power factor.

An exception occurs when the power factors $\cos\theta$, $\cos\theta_1$, $\cos\theta_3$, etc., are all equal, so that

$$E\,I = E_1 I_1 + E_3 I_3 + \ldots$$

In this case total apparent power is the sum of the apparent powers of the separate components, and, furthermore, the value of the total and separate power factors is not affected by any change in the relative amplitudes of the component electromotive forces and corresponding changes in component currents. This occurs when power factor is unity and in one special case, as discussed later.

Unity Power Factor Occurs only when the Current Wave is Precisely Similar to the Electromotive Force and in Phase with it. Reactance must be Zero and Resistance Constant. As power factor is real power $R\,I^2$, divided by apparent power $E\,I$, it is obvious that, in order to have unity power factor, $E\,I$ must equal $R\,I^2$ and $E = R\,I$. This can be true only in case the reactance of the circuit is zero and there is no capacity or inductance present.

Power factor is the ratio of resistance R to the impedance Z. This ratio is unity only when reactance is zero and the circuit contains resistance only. Furthermore, for unity power factor, the resistance must be constant, for it has already been shown that a pulsating resistance reduces power factor to less than unity

Constant resistance means that the current wave is similar to the electromotive force wave; the current i at any instant is proportional to the electromotive force e at that instant; $e = R\,i$. In this case the current and electromotive force pass through zero simultaneously and their maximum values coincide. Under no other circumstances can power factor be unity. There is no limit, however, to the irregularity of the current and electromotive force waves with unity power factor, provided the two waves are similar.

As a numerical illustration of unity power factor in case of a complex electromotive force, let the electromotive force $E = 50$, comprising a fundamental $E_1 = 40$ and a third harmonic $E_3 = 30$, be connected to a circuit with $R = 10$. The current is similar to the electromotive force; thus, $I_1 = 4; I_3 = 3; I = 5$. Power $R\,I^2 = R\,I_1^2 + R\,I_3^2$; or $250 = 160 + 90$. Apparent power $E\,I = 50 \times 5 = 250$. Power factor $= 1$. In like manner, the electromotive force may contain any number of harmonics and these may have any phase positions, as well as any amplitudes, for the phase of one harmonic with respect to others or with respect to the fundamental has no effect on power factor. For a more formal proof, see Bibliography, 23, 34.

Power Factor Less than Unity is due either to Current Displacement or Current Distortion. It will be seen that power factor is less than unity in two cases: (*a*). When an alternating current is shifted in phase with reference to the electromotive force, so that the zero and maximum values of current occur earlier, or later, than the corresponding zero and maximum values of electromotive force, power factor is less than unity, no matter what the wave forms of current and electromotive force may be. This is the common case and usually comes to mind when the power factor of an alternating current is referred to as being less than unity; the angle θ in the expression, power factor equals $\cos\theta$, represents a true phase displacement. (*b*). When current and electromotive force are unlike in wave form, power factor is less than unity, no matter what may be the phase position of the current with respect to the electromotive force; power factor may be brought to a maximum value by shifting the current wave with respect to the electromotive force, but this maximum is always less than unity.

The sign of θ, in the expression power factor equals $\cos\theta$, is ambiguous and does not indicate whether the current is lagging or leading. In fact, when the reduction in power factor is due to distortion, there may be neither lag nor lead. Thus, power factor 0.85, for example, indicates a phase angle of 32 deg. between the vectors I and E, representing current and electromotive force. If there is no lag or lead, the vector I is apparently caused to swing out of the usual plane of reference, as already referred to in the discussion of distortion due to pulsating resistance, inductance or capacity.

Either current displacement or current distortion may operate alone to reduce power factor, or the two causes may operate simultaneously. Customarily the two effects are lumped together in a single resulting power factor $\cos\theta$, which, in some cases, may be separated into two factors, $\cos\alpha$ due to current displacement and $\cos\beta$ due to current distortion. The angle α then represents lag or lead in the usual sense in the plane of reference and the angle β the amount the current vector

swings out of that plane due to distortion, power factor being the product cos α cos β. A single factor, however, is more convenient and is quite sufficient for ordinary purposes. The values of the two separate factors are not readily determined and, except in special cases, are not independent of each other, Bibliography, 59.

Peculiar Special Case. When the current wave is not similar to the electromotive force, any change in amplitude of any harmonic component changes the complex power factor, except in one peculiar case, namely, when only one harmonic, the nth harmonic, is present and the lag of the current of this harmonic with respect to its electromotive force is exactly equal to the lead of the fundamental current with respect to the fundamental electromotive force. This occurs when, in addition to a resistance, the circuit has a capacity reactance $1/C\ \omega$ which, for the fundamental, is n times the inductive reactance $L\ \omega$, Bibliography, 59.

In this case, and in this case only, the harmonic and fundamental have the same power factor, lagging in one case and leading in the other, and this is the power factor of the complex wave. Whether the complex current is lagging or leading with respect to the complex electromotive force is apparently indeterminate.

Suppose, with a suitable frequency mixer, Bibliography, 60, the relative values of fundamental and harmonic can be varied, so that the total r. m. s. value of the complex electromotive force remains constant. The current taken by the circuit, its real and apparent power and its power factor remain unchanged, as the wave form of the electromotive force is varied from 100 per cent fundamental with leading power factor, to 100 per cent harmonic with lagging power factor. When fundamental and harmonic are both present in any proportions, the current vector apparently swings around in space, maintaining a constant phase angle while changing from lagging to leading. In a somewhat similar way, current in a synchronous motor changes from lagging to leading, with increase of field excitation, without the power factor passing through unity, Bibliography, 49.

Conclusions. This paper, which is in itself a summary, may be further summarized by surveying the headings of the various paragraphs. It has been pointed out that there are well-known methods for obtaining the general solution for practically all problems dealing with simple harmonic alternating currents. There seems, however, to be no similar method that can be applied in all cases to the solution of problems when the currents are non-harmonic. Such problems have to be solved more or less separately, without a general solution. The purpose of this paper has been to present certain principles simply and clearly, in order that use may be made of them wherever applicable.

Attempts to use some kind of distortion factor, Bibliography, 44, for modifying the usual alternating current solutions, so that equations and graphical diagrams based on the sine assumption may be extended so as to apply to non-sine currents, have not borne fruit, Bibliography, 34, 45, nor has a general analytical discussion of non-sine alternating currents given practical working solutions, Bibliography, 48. Although certain general principles are established, they do not afford the immediate solution of every particular problem.

An outstanding fact is that graphical diagrams for precisely representing non-harmonic alternating currents and electromotive forces require, except in some special cases, more than two dimensions. The ordinary plane diagrams are at best only approximations.

It is a consolation to know, however, that the errors in plane diagrams are commonly not large enough to assume importance, Bibliography, 40, p. 228, except when leading as well as lagging currents are involved, in other words, except in circuits containing capacity reactance, as in condensers and synchronous machinery.

In inductive circuits, harmonics are, to a certain extent, choked out, so that errors are limited and there is no tendency for them to become amplified. The errors may be likened to the errors in using a drawing accurately made on a rumpled paper, which is later ironed out flat. The flat diagram, although not precise, may be accurate enough for most purposes. Thus, transformer diagrams drawn in a plane give excellent working results, despite wave distortion. In a synchronous motor, on the other hand, certain discrepancies due to current distortion may be corrected or eliminated by use of a diagram in three dimensions, Bibliography, 49. It is well known that the power factor of a synchronous motor does not become unity when current changes from lagging to leading, as the plane diagram and usual theory based on the sine-wave assumption would indicate. The three-dimensional diagram makes it possible for the current vector, in passing from lagging to leading, to swing around in space so that the power factor passes through a maximum less than unity.

Plane diagrams are subject to the greatest errors in case of circuits containing inductance and capacity, when resonance for a particular harmonic may greatly amplify the errors due to wave distortion.

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Abridgment of

High-Voltage Measurements on Cables and Insulators

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Member, A. I. E. E.

***Synopsis.**—This paper presents some of the results of a series of high-voltage tests on cables and insulators, extending over a period of eight years, to determine the electrical characteristics of the insulation. Leakage current, insulation resistance, and watt input tests were made with direct and alternating current. Paper-insulated and rubber-insulated cables and a 27,000-volt porcelain insulator were tested.*

From these tests several conclusions were drawn, the principal ones being as follows:

1. Insulation resistance of paper and rubber-insulated power cables increases to a maximum with increasing applied d-c. voltage, the characteristic depending upon the temperature.

2. It is necessary to use shields as well as guards in making tests to determine the electrical characteristics of cable insulation under d-c. voltage stresses above the ionization point.

3. The watt input to the insulation of a paper cable under d-c. stress, at a given temperature, depends upon the character of the voltage wave; the greater the ripple, the greater the watt input.

4. It is necessary to use shields as well as guards in making tests on short cable samples to determine the a-c. electrical characteristics, such as dielectric loss of cable insulation under voltage stresses above the ionization point.

5. The ionization point is very variable depending upon the physical circuit, together with the atmospheric conditions, and represents, in reality, local air breakdown.

6. The better (i. e., the more uniform) the dielectric, the greater is the tendency for the material to break down in its entirety rather than at a single point. Practically, of course, no dielectric is perfectly homogeneous, so that failure will be restricted to the weakest spot or spots.

Tests on Paper-Insulated Cables

THE first series of tests described in the paper is that on paper-insulated, lead-covered cables. These were tested with direct current from a kenotron set and a high-voltage battery and with 60-cycle alternating current.

The results of the tests were plotted to show the variation of leakage current, insulation resistance and watt input with applied voltage at given temperatures. These curves show the insulation-resistance-voltage stress and watt input voltage stress characteristics of the cables.

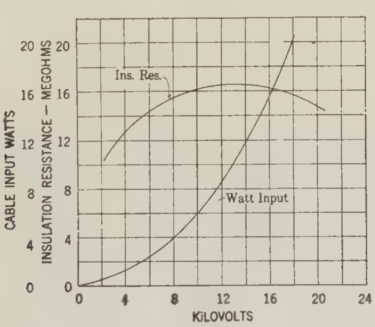

Fig. 1—Variation of D-c. Characteristics (Insulation Resistance and Watt Input with Voltage) of Old 13,800-Volt Paper-Insulated Cable Line

Tests made on Line 5-97, consisting of rosin-oil impregnated, three-conductor, 4/0 copper cable, 18,283 ft. long. Conductor insulation, 7/32 in., outer belt, 7/32 in.

Voltage applied from kenotron and low voltage battery. Corrections made for temperature changes.

Insulation Resistance Varies with Voltage Applied. The first conclusion, namely, that insulation resistance increases to a maximum with increasing applied d-c. voltage, is supported by the tests the results of which are shown in Figs. 1 to 6 and 10 to 14, inclusive.

An inspection of these curves indicates that both old and new cables show this characteristic in varying degree, depending upon the temperature. At the lower temperatures the insulation-resistance rise is very pronounced, but at the higher temperatures the rise is slight.

Effect of Temperature on Variation of Insulation Resistance with Applied D-c. Voltage. The effect of temperature is shown in Fig. 3 for two new paper cables (A and B) of different types. Further temperature effects upon the insulation-resistance-voltage-stress characteristics are shown in Figs. 4 and 5, for new C and old D paper cable, respectively.

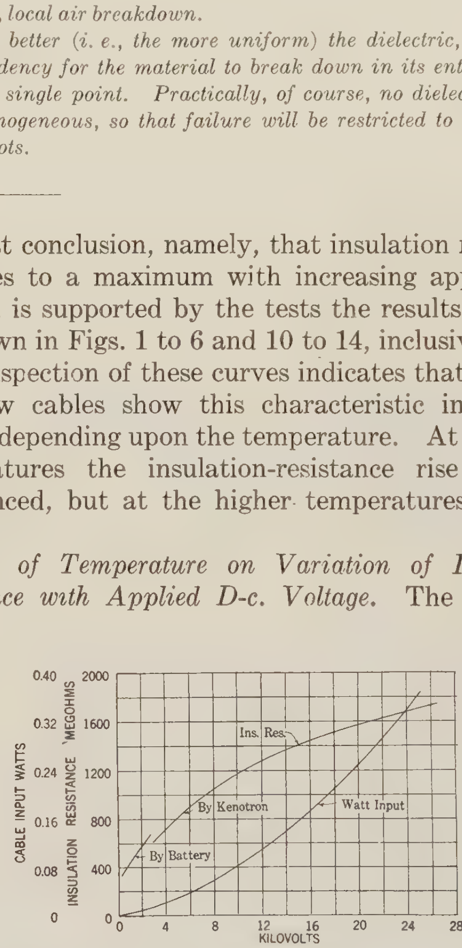

Fig. 2—Variation of D-c. Characteristics of New 15,000-Volt Paper-Insulated Cable Line

Tests made on Line 38-118, consisting of petrolatum impregnated, three-conductor, 300,000 cir. mils cable, 22,079 feet long. Conductor insulation 7/32 in., belt, 3/32 in.

Voltage applied from kenotron and low voltage battery.

Necessity for Using Shields. In making tests to

1. Edison Electric Illuminating Co., Boston, Mass.

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determine the electrical characteristics of reel lengths of cables it became evident that complete shielding is very important. Figs. 3, 4, 5, and 6 illustrate cable characteristics measured without shields. In these figures most of the insulation-resistance curves against

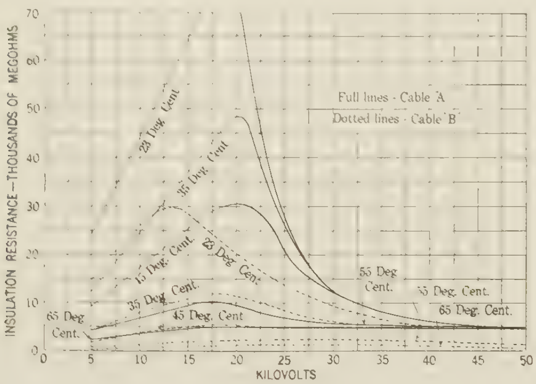

Fig. 3—Variation of Insulation Resistance with D-c. Voltage, at Several Temperatures, of Unshielded Reels of New Paper-Insulated Cable

Tests on 15,000-volt, three conductor, 350,000-cir. mil cable lengths. Conductor insulation 7/32 in., belt 3/32 in. Cable A, 644 feet long; petrolatum-impregnated; cable B, 645 feet long, impregnated with petrolatum and rosin-oil.

Voltage applied from kenotron.

voltage stress rise to maximum and then decline. This decline is apparently due to ionization of the air, either within or outside the cables. The effect of the ionization of the air at the ends of the cable becomes proportionally less as the leakage current through the

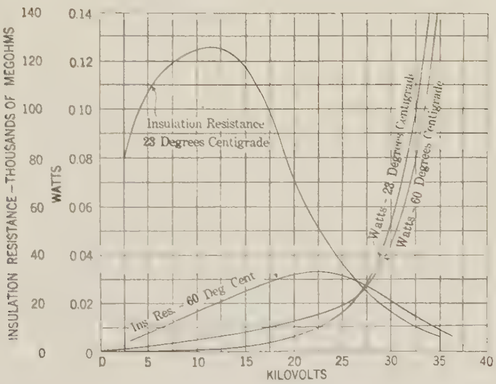

Fig. 4—Variation of D-c. Characteristics at Two Temperatures of Guarded, Unshielded Reel of New Paper-Insulated Cable

Tests made on cable C, 15,000-volt, three-conductor, 300,000 cir. mils, petrolatum-impregnated, 800 feet long. Conductor insulation 7/32 in., belt 3/32 in.

Voltage applied from kenotron.

insulation increases; in fact, in case of very high leakage through the insulation, it may be a negligible percentage of the total measured current.

Where the leakage current is low, however, the end effects may equal or completely swamp the cable insulation effect at stresses above the ionization point. In these cases, whether the cable is long or short, it is necessary to use shields and guards to obtain the true leakage current values through the insulation, from which values the cable characteristics are derived.

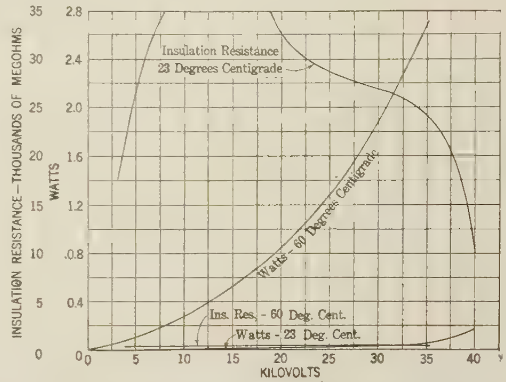

Fig. 5—Variation of D-c. Characteristics at Two Temperatures of Unshielded Reel of Old Paper-Insulated Cable

Tests made on cable D, 15,000-volt, three-conductor, 2/0, rosin-oil impregnated, 101 feet long. Conductor insulation 9/32 in., belt 9/32 in.

Voltage applied from kenotron.

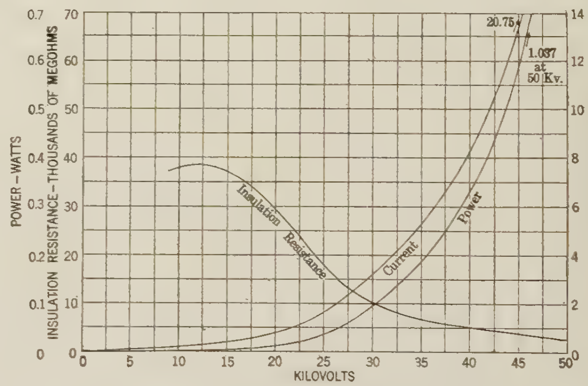

Fig. 6—Variation of D-c. Characteristics (Leakage Current, Insulation Resistance, and Watt Input with Voltage) of Unshielded Reel of New Paper-Insulated Cable

Tests on cable C (see Fig. 4). Voltage applied from high-voltage battery. Temperature 26–29 deg. cent.

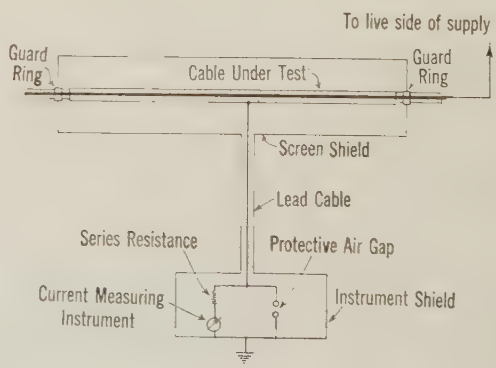

Fig. 7—Diagram of Connections for Tests with Cable and Instruments Shielded

Further tests were made, therefore, on cable C using shields and the results are given in Figs. 10, 11, and 14. These results support the second con-

clusions, that it is necessary to use shields as well as guards in making tests to determine the electrical characteristics of cable insulation under d-c. voltage stresses above the ionization point.

The term "shielded guarded" means that a complete system of shielding was used in making these tests in addition to the ordinary guards or guard rings. This system of shields, in the case of the paper cable, is

Fig. 8—Shield for Reel of Cable

diagrammatically outlined in Fig. 7. The actual cable and instrument shields are shown in Figs. 8 and 9, respectively. From Fig. 7, it will be noted that the cable, measuring instruments, and connections are completely shielded.

Figs. 10 and 11 were obtained with shields and guards, and No. 6 without them on an 800-ft. length of 15,000-volt paper cable C. It will be noted that the shielded guarded values are only a fraction of the unshielded unguarded values at the higher stresses.

It will be observed that the leakage current and watt

Fig. 9—Shield for Measuring Instruments

input at 50 kv., unshielded, unguarded are 43 times the shielded guarded, or true values.

Fig. 12 shows the comparisons between the characteristic curves of insulation resistance against voltage stress with and without shields and guards. From an inspection of Fig. 12, it appears that the curves of insulation resistance under the two conditions diverge at stresses far below the usual so called ionization point. There is a marked divergence at 10 kv. d-c. It will be noted that the shielded guarded curve continually rises and it might be inferred that it must reach a maximum and decline previous to failure due perhaps to the ionization of the air within the insulation.

Fig. 16 shows the total end loss in watts, which is the difference between the unshielded unguarded and shielded guarded results, plotted against voltage stress. This curve evidently represents the power dissipated into the air at the various d-c. stresses.

It is obvious that the value of watts will increase rapidly with the higher voltages and is subject to the

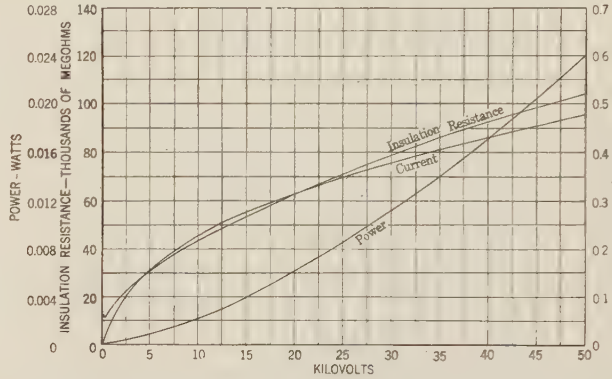

Fig. 10—Variation of D-c. (Battery) Characteristics on Shielded Reel of New Paper-Insulated Cable

Tests on cable C (see Fig. 4). Voltage applied from high-voltage battery. Temperature 26-29 deg. cent.

local atmospheric conditions at the ends of the cable.

These results lead the author to believe that nearly all laboratory tests on cables and other insulations under d-c. stresses must be made with shields as well as guards in order to secure true and accurate results. Further,

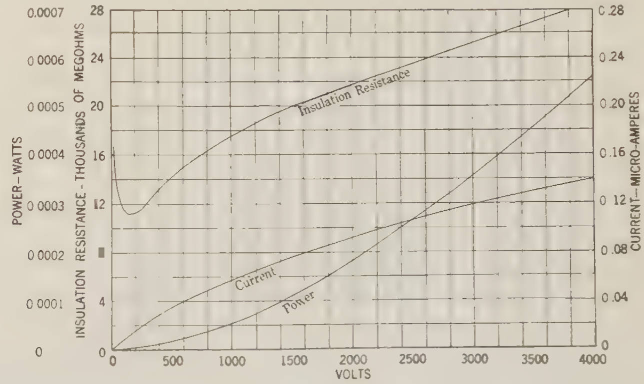

Fig. 11—Variation of D-c. (Battery) Characteristics of Shielded Reel of New Paper-Insulated Cable

Results of Fig. 10 plotted to larger scale

it is believed that such shields are necessary at stresses far below the ordinary ionization point.

The need for the shield is due to the fact that the end effects are composed of surface leakage and leakage through the air. The guard takes care of the surface leakage and the shield takes care of the leakage through the air at the end of the cable.

The use of guards or guard rings is an old practise and some observers have used shields for instruments, but the author believes that the use of shields on the cable or dielectric under test is new and also very vital. These shields and guards are necessary in all cases where the end effects are of sufficient magnitude to interfere with the determination of the true d-c. leakage current through the insulation.

The relative effects of the guard and shield have not been fully determined as yet. From such preliminary

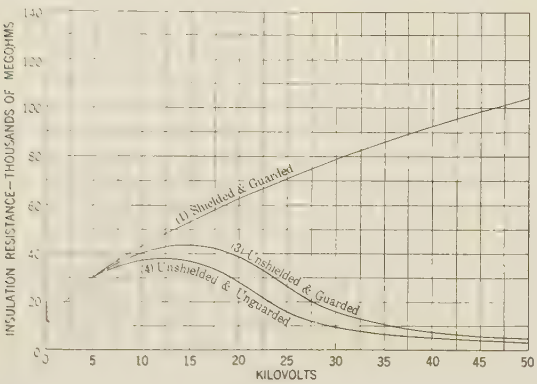

FIG. 12—CURVES SHOWING EFFECT OF SHIELDING AND GUARDING ON MEASURED INSULATION RESISTANCE OF REEL OF NEW PAPER-INSULATED CABLE

Tests on cable C (see Fig. 4). Voltage applied from high voltage battery. Temperature 26-29 deg. cent. (Includes data of Figs. 6 and 10)

work as has already been done, it appears that the shield effect predominates over the guard effect under d-c. stresses and that this predominance is very marked at the higher d-c. stresses.

An inspection of Figs. 10, 11, 13 and 14 indicates that

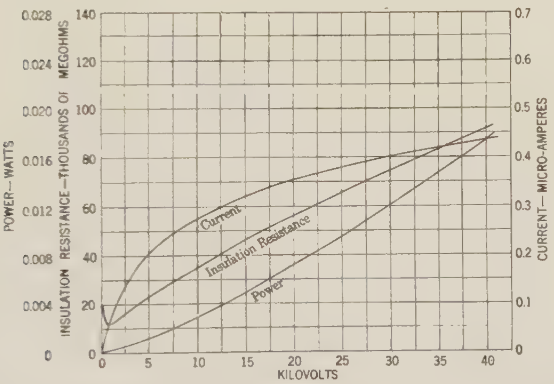

FIG. 13—VARIATION OF D-C. (KENOTRON) CHARACTERISTICS OF GUARDED SHIELDED REEL OF NEW PAPER-INSULATED CABLE

Tests on cable C (see Fig. 4). Voltage applied from kenotron. Temperature 26 deg. cent.

with both battery and kenotron d-c. stress, the insulation resistance curves show a slight drop at the start before the general rising characteristic begins. It is thought that this results from either a residual electrification or a change within the insulation. This reverse action is perhaps important as indicating a complete change of conditions within the dielectric.

The various curves presented show that the insulation resistance of modern paper cables under shielded conditions is exceedingly high and increases with increasing applied d-c. stress up to certain limits. From the operating standpoint, perhaps it may be worthwhile to have a certain amount of leakage in a long cable to act as a safety valve when the line is subjected to a

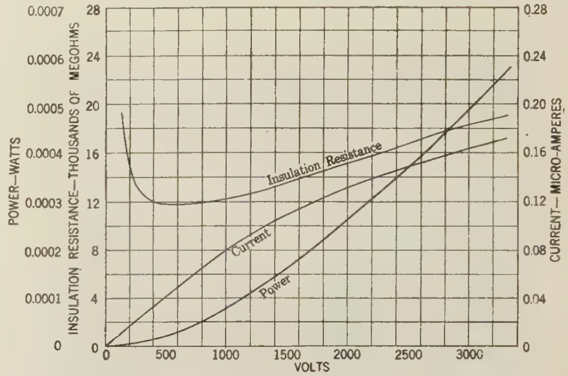

FIG. 14—VARIATION OF D-C. (KENOTRON) CHARACTERISTICS OF GUARDED, SHIELDED REEL OF NEW PAPER-INSULATED CABLE

Results of Fig. 13 plotted to larger scale

high transient voltage. In other words, perhaps a certain amount of leakage acts as a stabilizer provided that in obtaining this leakage there is no unnecessary sacrifice of dielectric strength.

Comparison of Battery and Kenotron Tests. Shielded guarded Figs. 10 and 11 obtained by use of the Cruft high-voltage battery may be compared with Figs. 13 and 14 by kenotron, for the 800-ft. length of 15,000-

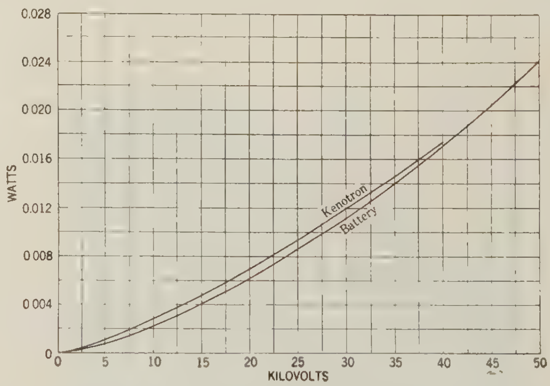

FIG. 15—COMPARISON OF WATT INPUTS WITH KENOTRON AND BATTERY ON SHIELDED REEL OF NEW PAPER-INSULATED CABLE

Data of Figs. 10 and 13

volt paper cable *C*. The results are quite similar, but the watt input with the kenotron is a little higher than that with the battery source. This is shown by Fig. 15. It is believed that this is due to the ripple of the kenotron wave.

From this the third conclusion is drawn, that the watt input to the insulation of a paper cable under d-c. stress, at a given temperature, depends upon the character of the voltage wave; the greater the ripple, the greater the watt input. This would agree with the

accepted fact that the watt loss in a dielectric increases with frequency. In other words, the watt loss in a dielectric at given ambient temperature ranges from a minimum on direct current with wave form better than that supplied by battery, to a maximum at high frequency.

A-c. Dielectric Loss Tests, Shielded and Unshielded. The failure of insulation is largely a matter of heat

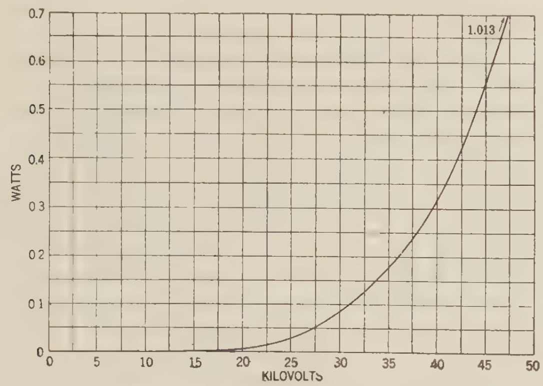

Fig. 16—Variation of Watts End Loss with D-c. Voltage (Battery) on Reel of New Paper-Insulated Cable

Tests on cable C (see Fig. 4). Voltage applied from high-voltage battery. Temperatures 26-29 deg. cent. Data from Figs. 6 and 10

and its relative distribution in the material. Under d-c. stress the watt input and the consequent heating is very slight in comparison with that under so called equivalent a-c. stresses.

Fig. 17 shows the curves of a-c., 60-cycle watt input

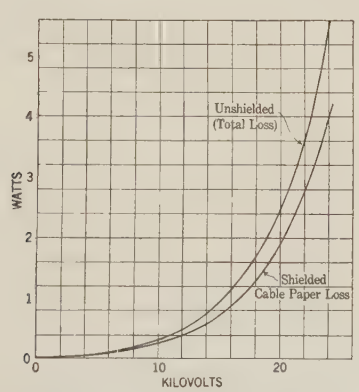

Fig. 17—Variation of Watt Inputs with 60-Cycle Voltage on Short Lengths of New Paper-Insulated Cable, Shielded and Unshielded

Tests made on cable G, 15,000-volt, three conductor, 300,000 cir mils, petrolatum-impregnated, 24 ft. long. Conductor insulation 7/32 in., belt 3/32 in.
Voltage applied from 60-cycle source. Temperature 25 deg. cent.

(dielectric loss) against voltages stress for a 24-ft. length of 15,000-volt paper cable *G* with and without shields and guards. On such a short cable the a-c., 60-cycle end losses are not negligible and shields and guards are necessary to insure proper accuracy of dielectric loss measurements at stresses above the ionization point.

The term end loss as used is the total end loss or difference between the unshielded unguarded value and the shielded guarded one as previously outlined in the case of the d-c. tests. The relative effect of shield and guard is very difficult to obtain because all guards act as shields. Leakage taking place 1/1000 of an in. above the surface of the paper is leakage through the air. Any guard ring intercepts this as well as the true surface leakage. All tests made so far have shown different values with and without shields even if guard rings were left on during the latter condition.

The error of 34 per cent in the unshielded unguarded

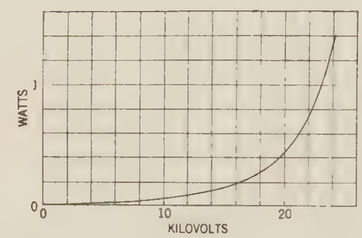

Fig. 18—Variation of Watts End Loss with 60-Cycle Voltage on Short Length of New Paper-Insulated Cable

From data of Fig. 17

measurements indicates the necessity for using shields and guards in making measurements of a few watts loss under stresses around 24,000-volts a-c. From this, it may be deduced that unshielded unguarded watt loss measurements on cable samples of 10 ft. or less under a-c., 60-cycle, 24,000-volt stresses might be 100 per cent in error. The author believes that this is one of the reasons why dielectric loss measurements

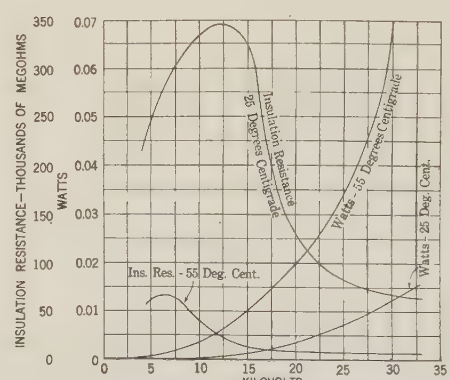

Fig. 19—Variation of D-c. Characteristics (Leakage Current, Insulation Resistance, and Watt Input with Voltage) at Two Temperatures of Unshielded Reel of New Rubber-Insulated Cable

Tests made on cable E, 10,000-volt, single conductor, 4/0, 7/32 in. insulation, 505 feet long
Voltage applied from kenotron

taken at different laboratories and more especially those on short lengths of cables as against long lengths, have sometimes failed to agree in the past.

From the foregoing results the fourth conclusion has been drawn that it is necessary to use shields as well as guards in making tests on short cable samples to

determine the a-c. electrical characteristics, such as dielectric loss of cable insulation under voltage stresses above the ionization point.

Fig. 18 shows the variation of total watt end loss with voltage stress. This loss is made up of surface and air electrical leakage as in the previous cases. Further preliminary tests have indicated that the guard effects vary depending on the relative position of the guard ring to the copper conductor and the lead sheath.

Ionization Point is Indeterminate. It will be ob-

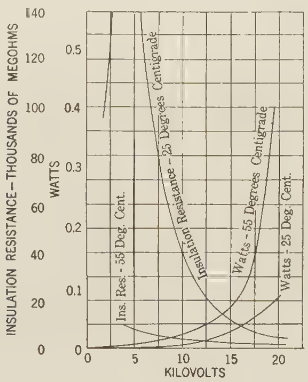

FIG. 20—VARIATION OF D-C. CHARACTERISTICS AT TWO TEMPERATURES OF UNSHIELDED REEL OF OLD RUBBER-INSULATED CABLE

Tests made on cable F, 10,000-volt, single-conductor, 4/0, 7/32 in. insulation, 319 feet long.
Voltage applied from kenotron

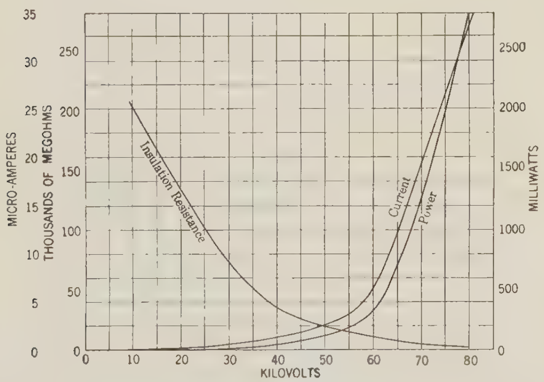

FIG. 21—VARIATION OF D-C. CHARACTERISTICS OF UNSHIELDED LENGTH OF NEW RUBBER-INSULATED CABLE

Tests made on cable H, 10,000-volt, single-conductor, No. 6, 7/32 in. insulation, 89 feet long
Voltage applied from kenotron

served that the difference between the shielded guarded and unshielded unguarded measurements steadily increases with increasing stress. The difference probably represents the increasing air loss at the ends of the cable. It will be noted that these curves (Fig. 17) diverge at even the lower stresses, as in the case of the previous d-c. tests shown in Fig. 12.

From this and the previous results, the fifth conclusion is drawn: that the so called ionization point is very variable depending upon the physical circuit together with the atmospheric conditions and represents in reality, local air breakdown. This is supported by the tests with direct current on paper and rubber cables as well as by the a-c. tests on paper cable. In all cases the curves with and without shields and guards diverge at the lower values of stress below the commonly accepted ionization point.

From this, it may be deduced that the air conducts at

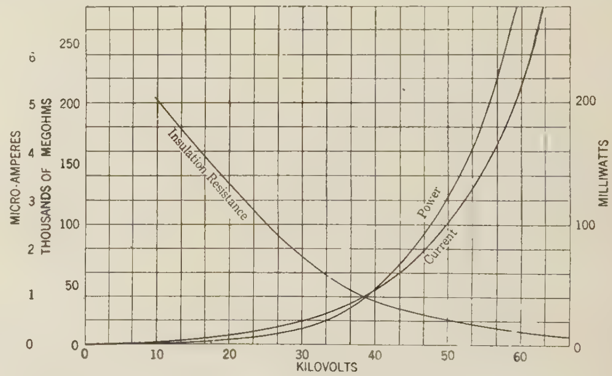

FIG. 22—VARIATION OF D-C. CHARACTERISTICS OF UNSHIELDED LENGTH OF NEW RUBBER-INSULATED CABLE

Data of Fig. 21 plotted to larger voltage scale.

all stresses both direct current and alternating current and that ionization points represent local air breakdown due to the local physical circuit, atmospheric and stress conditions.

TESTS ON RUBBER-INSULATED CABLE

Tests similar to those on the paper-insulated cables were made also on rubber-insulated cables.

Insulation Resistance Varies with Voltage Applied. A new and an old rubber cable showed the same general

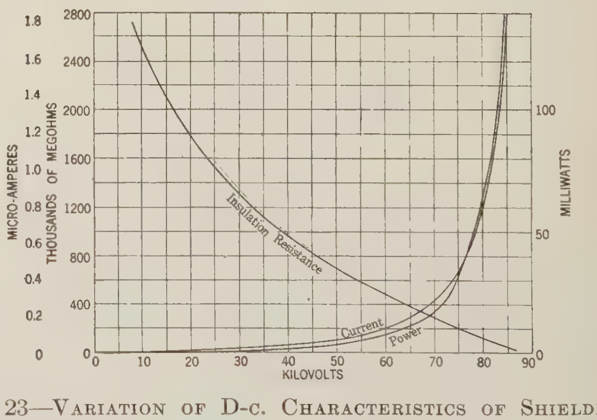

FIG. 23—VARIATION OF D-C. CHARACTERISTICS OF SHIELDED LENGTH OF NEW RUBBER-INSULATED CABLE

Tests made on cable H (See Fig. 21). Voltage applied from kenotron

insulation-resistance-voltage-stress characteristic at 25 deg. cent. as did the paper-insulated cables. Figs. 19 and 20, giving results of tests on cables *E* and *F*, respectively, illustrate this.

A series of d-c. tests by kenotron was made on an 89-ft. length of new 10,000-volt rubber cable *H*, both with and without shields. In these tests, the stresses were carried up to the breakdown point. The

results are shown by Figs. 21, 22, 23, 24 and 25. The same shields and test set-ups were used as in the case of the paper cable.

From the curves, it will be noted that the insulation-resistance-voltage-stress curve, at room temperature, continually falls from the 10-kv. point. It is probable that at stresses below 10 kv., the curve would show a rising characteristic.

It is apparent that the leakage current and input

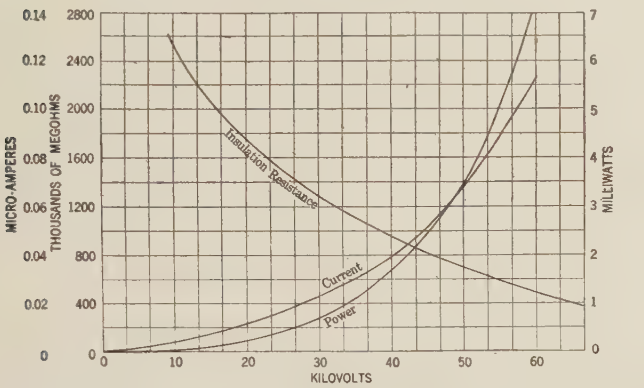

Fig. 24—Variation of D-c. Characteristics of Shielded Length of New Rubber-Insulated Cable

Data of Fig. 23 plotted to larger voltage scale

watts rise very rapidly after the critical point of 60 kv. is reached under the unshielded condition. This is probably due to the ionization of the external air surrounding the ends of the cable.

On the other hand, the abrupt rise under shielded conditions does not occur until 70 kv. is reached. This must be due to the ionization of the air entrapped in the

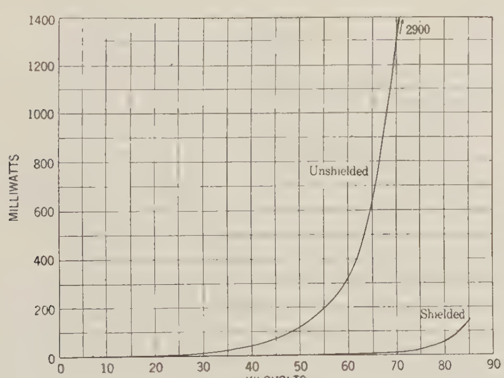

Fig. 25—Comparison of Curves of Watt Input with D-c. Voltage on New Rubber-Insulated Cable, Shielded and Unshielded

Tests on cable H (see Fig. 21). Data of Figs. 21 and 23

dielectric itself. It would thus appear that the ionization of the external air around the cable ends takes place before the ionization of the air entrapped in the insulation, unless the test results are seriously modified by the action of surface leakages.

Effect of Shields. The effect of shielding and guarding is very marked in these tests as in the case of the paper cable. It will be observed that the true loss is only 1/44 of the apparent or unshielded unguarded loss at the given stress. The relation is shown graphically by Fig. 25.

The use of shields as well as guards is thus absolutely necessary in making d-c. measurements on short rubber

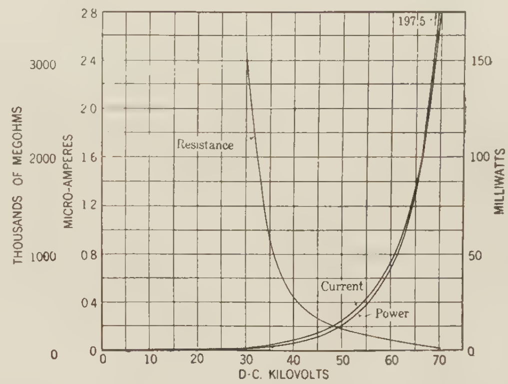

Fig. 27—Variation of D-c. Characteristics (Leakage Current, Insulation Resistance and Watt Input with voltage) of Unshielded 27,000-Volt Pin-Type Line Insulator

Voltage applied from kenotron

cables at high stresses in order not only to insure the accuracy of results but to determine the true characteristics of the cable insulation.

Insulation Failure. Fig. 23 shows the true shielded guarded insulation-resistance-voltage-stress curve from

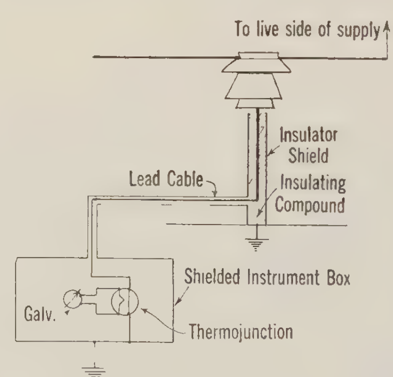

Fig. 28—Diagram of Connections for Measurements on Shielded Line Insulator

10 to 85 kv. Under the shielded condition, at approximately 84 kv., the curves of leakage and watt input are rising very rapidly and are nearly perpendicular to the abscissas (voltage stress). This, of course, indicates that the dielectric is about to fail. As a matter of fact, failure did take place at 85 kv. Upon examination, this new rubber cable was found to be literally riddled with incipient faults. The rubber insulation had been stressed far above its safe or electrical elastic limit, and a general deterioration had set in.

This leads to the sixth conclusion, that the better,

i. e., the more uniform the dielectric, the greater the tendency for the material to break down in its entirety rather than at a single point. Practically, of course, no dielectric is perfectly homogeneous, so that failure will take place at the weakest spot or spots. From this it might be deduced reasonably that the better the insulation the more care should be taken not to over-stress it. Such over-stressing, while not producing actual failure, must deteriorate and weaken the whole insulation. It might be further deduced from this that there must be an electrical elastic limit in dielectrics

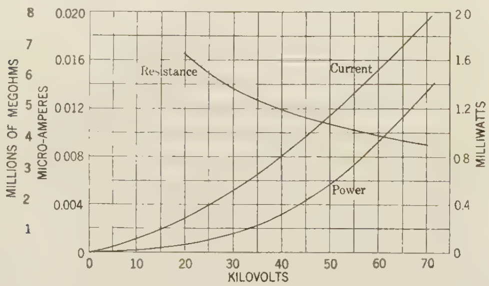

Fig. 30—Variation of D-c. Characteristics of Shielded 27,000-Volt, Pin-Type Line Insulator

Same insulator as in Fig. 27. Voltage applied from kenotron

analogous to the physical elastic limit in metals. If the stress exceeds this limit a strain and eventual failure is the result.

Tests on a Line Insulator

Besides the tests on paper and rubber cables a similar series has been made on a 27,000-volt porcelain line insulator, both with and without shields. Fig. 28 shows the diagrammatic arrangement.

Results of D-c. Tests. Figs. 27 and 30 show the d-c. unshielded and shielded test results. It will be noted that the shielded insulation-resistance-voltage-stress curve has a slowly falling characteristic from 20 kv. upward. It is believed that this curve would have been nearly flat if the shield had been brought closer to the porcelain.

From these curves, it will be noted that the shielded value of insulation resistance falls rather slowly and that the watt input is not increasing very rapidly at 70 kv., which is a low stress for the insulator. The porcelain apparently presents a more nearly constant resistance to electrical stress than impregnated paper and rubber insulation.

The unshielded curves show the effect of the electrical leakage through the air around the outside of the insulator. At 60 kv. the leakage and watt input curves rise very abruptly as in the case of the rubber cable. This is probably due to the ionization of the external surrounding air. The shielded curves (Fig. 30) of leakage current and watt input do not even show a rapidly rising characteristic at 70 kv. direct current.

Results of A-c. Tests. Fig. 31 shows the results for the same insulator under a-c., 60-cycle stresses. These results indicate that shields are necessary to obtain true readings under a-c., 60-cycle stresses.

It will be noted that the impedance voltage-stress curves are nearly flat, perhaps indicating that the insulator is well within its safe electrical stress limits. If, in future tests, these curves can be carried through the lower and higher ranges, undoubtedly new and valuable data can be obtained.

Remarks and Suggestions

In all these tests and researches, the attempt has been made to determine the insulation-resistance-voltage-stress curve and the watt-input voltage-stress curve. It is believed that if such curves can be obtained for various insulations under electrical stresses, both direct current and alternating current of various frequencies from zero to breakdown at several temperatures, then the way will be opened for the practical study and determination of dielectric action under electrical stress.

The work covered by this paper involved for the most part d-c. stresses and it is not known how far the results reflect the action of the insulating material under a-c. stresses. From the d-c. standpoint, it might well be argued that the insulation-resistance-voltage-stress curves are a measure of insulation condition. As long as the resistance increases with increasing voltage stress the insulation might be said to be on the safe side. The maximum value would then be the electrical

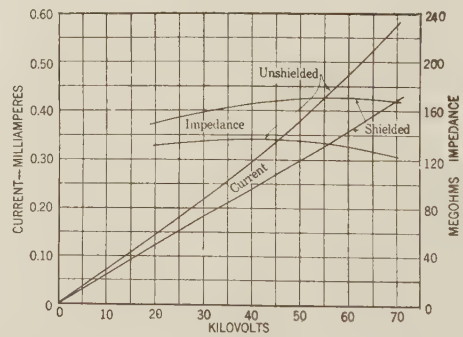

Fig. 31—Variation of Current and Impedance with 60-Cycle Voltage on 27,000-Volt, Pin-Type Line Insulator, Shielded and Unshielded

Same insulator as in Fig. 27. Voltage applied from 60-cycle source

elastic limit and the falling portion of the curve would represent the tendency of the insulation to deteriorate or electrically age. A sharp drop in the insulation resistance curve would indicate impending breakdown.

If this d-c. picture represents also the a-c. situation then a new means is provided for studying insulation under electrical stress. A large amount of a-c. research, however, must be conducted and matched against the direct current before these conclusions are justified.

The problem is further complicated because the d-c. insulation-resistance-voltage-stress curves vary widely with temperature, and the application of the higher

a-c. stresses produces a temperature change in the insulation.

The author believes that continuation of this line of investigation will open the way for a real practical study of dielectric phenomena.

Data on Test Methods, Istruments, Etc.

All tests and research work were carried on by the Standardizing and Testing Department of The Edison Electric Illuminating Company of Boston except those recorded in Figs. 3, 4, 5, 19 and 20, which were made by graduate students of the Massachusetts Institute of Technology at the suggestion of the Standardizing and Testing Department.

The tests and research work were performed at the substations and laboratory of the above company, at the Massachusetts Institute of Technology, and at the Cruft Laboratory of Harvard University.

Acknowledgments

The author wishes to express his appreciation to Professor G. W. Pierce and Professor E. L. Chaffee, of Harvard University, for the use of the 100,000-volt storage battery, and to Dr. V. Bush of the Massachusetts Institute of Technology for his cooperation and assistance in the matter of thesis tests.

The author thanks Messrs. T. M. Burkholder, D. E. Replogle, E. E. Piepho and J. E. Handy for their theses, and appreciates the work of the members of the staff of the Standardizing and Testing Department of The Edison Electric Illuminating Company of Boston, particularly Messrs. H. C. Hamilton, R. W. Chadbourn, C. H. Smith and W. B. Elmer.

Abridgment of

Studies on Sparking in Air

BY A. PEN-TUNG SAH*

Associate, A. I. E. E.

Synopsis.—*Sparking voltages and gradients in air between spheres of unequal diameters and between two cylinders placed with their axes perpendicular to each other in space (called cross-cylinders) have been determined. Complete tables giving the coefficients of gradient corresponding to any given spacing and radii, have been tabulated, the formulas used being those of Kirchhoff and Russell. For cross-cylinders, an approximate formula has been developed.*

In the theoretical discussions, the more definite form of the theory of ionization by collision as given by Bergen Davis has been extended to the sphere-gap and a relation has been deduced to account for the variation of the sparking gradient as investigated in the first part of this work, which is in substantial agreement with those found by F. W. Peek, A. Russell and others.

* * * * *

Introduction

SPARKING voltages and gradients between needle-points and spheres have been measured by many investigators. It has been theoretically shown[1] that the relation between the sparking voltage and the spacing, when the spacing is so large that corona precedes a spark-over, should conform to a linear law. Such is, in fact, the case for the needle-gap, as shown by F. W. Peek[2] and others. For spheres, it has also been shown by Peek[3] and A. Russell[4] that for large spacings under twice the radius of the spheres, the results seem to indicate a constant sparking gradient for a given size of spheres when both of them are insulated and are at equal and opposite potentials, the middle of the high voltage winding of the transformer being connected to earth. As for the case when one of the spheres is grounded with the high potential applied to the other insulated sphere, all experimental data seem to contradict this view.[3-12] In this case, the sparking gradient decreases rapidly at first and then gradually increases with the spacing.

The existing theory to explain these phenomena is mainly due to Peek, who assumes that air has a constant dielectric strength, an assumption fairly well borne out by the corona measurements on concentric cylinders and parallel wires. Inasmuch as this theory was extended from the phenomenon of corona, it seems advisable to study the problem of sparking in air by using different kinds of electrodes, namely, two spheres of unequal diameters and two cylinders placed with their axes perpendicular to each other in space (called cross-cylinders, for brevity) to see if similar relations exist and to derive a law for sparking based on the more definite form of the theory of ionization as first formulated by J. S. Townsend and later extended by Bergen Davis to the corona measurements on concentric cylinders and parallel wires. It is thus seen that the present investigation falls into two parts: namely, the determination of the sparking voltages and gradients for the above types of electrodes, and the formulation of a theory to explain the more or less empirical relation of Peek and Russell based on the known laws of ionization by collision.

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1. For all references see Bibliography.

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Part I

Sparking Voltages and Gradients Between Unequal Spheres and Between Cross-Cylinders

Formulas and Tables for the Calculation of the Maximum Gradients between Unequal Spheres and Cross-Cylinders. The case of two conducting spheres is of classical interest, being among the problems first successfully solved by Poisson by using his famous integral. Clerk Maxwell[13] also gave a solution but it was too complicated to be of any service in a numerical work. The first workable formula was given by Kirchhoff[14]. It was put in a manageable form by A. Russell[15], who proved the case for two equal spheres by the method of an infinite series of images, while G. R. Dean[16] solved the same problem by using hyperbolic functions and zonal harmonics. In the appendix* to follow, it will be shown how Russell's reasoning can be extended to the general case of two spheres of unequal diameters. From the proof it will be seen that the gradient at the surface of the spheres on the line of centers may be calculated from the following relations:

$$G_1 = V_1 F_{11}/X - V_2 F_{21}/X$$

and

$$G_2 = V_2 F_{22}/X - V_1 F_{12}/X$$

in which X = spacing between the spheres, G_1 = the gradient at the surface of the smaller sphere, V_1 = the voltage on the smaller sphere, and G_2 and V_2, the corresponding values for the larger sphere. The different F's will be called *coefficients of gradient*. The double subscript adopted is similar to the notation used in electrostatics for the coefficients of capacity, or of induction, or of potential. By giving appropriate values to the different V's, these general formulas will be found to be applicable to the different arrangements that are investigated: namely, when $V_1 = -V_2 = V/2$, the case when both spheres are at equal and opposite potentials, V being the potential difference between them; and when $V_1 = O$ or when $V_2 = O$, the two cases when one of the spheres is grounded. Thus for the case when both spheres are insulated and are at equal and opposite potentials, the two coefficients of gradient may be taken as:

$$F_1 = (F_{11} + F_{21})/2, \text{ and } F_2 = (F_{22} + F_{12})/2,$$

respectively.

The various F's are expressed in convergent series, the arguments of which are functions of the ratios b to a, ratio of radii, and X to a, ratio of spacing to the smaller radius. The values for these when $b = a$, *i. e.*, when the spheres are equal, have been given by other investigators[illegible].

For ready reference and interpolations, Figs. 1, 2, 3 and 4 giving values of F_{11}, F_{21}, F_{22}, and F_{12} are herein attached.

For the case of cross-cylinders, because of the lack of symmetry, it was not possible to obtain an exact solution of the problem by using known methods of mathematical analysis. In Appendix II, an attempt has been made at an approximate solution, the basic principle of which is quite similar to that employed by Dean[18] in deriving an approximate solution for two equal spheres. It will be seen that for the case in which both equal cylinders are insulated and are at equal and opposite potentials, the coefficients of gradient F are given by the following table of values, using which the values of the maximum gradient can be calculated from the relation:

$$G = \sqrt{2}\, V F/X$$

where G is the gradient, V the effective potential difference, and X the spacing.

Apparatus, Method of Measurement, Etc. Five sizes of spheres were used in the investigation, their diameters as measured by calipers being 25.0 cm., 20.2 cm., 15.0 cm., 10.0 cm. and 5.05 cm. They were made by soldering together two hemispherical bowls that were spun from copper. Their shape was quite satisfactory, as measurements of the curvature by means of a spherometer did not vary more than one per cent. The shanks were brass tubes, projecting 60 cm. from the spherical surface, each tube having a diameter about one-eighth of that of the sphere to which it was fitted. For the determination of sparking between a sphere and a plane, sphere of infinite radius, two sizes of plane surfaces were used, one being about 50 cm. in diameter and the other 150 cm. At short spacings, it was found that the determinations were practically the same, using either plate. Only when the spacing became large, about one-sixth of the diameter of the plate, did deviations begin to appear. From this, it was concluded that with the 150-cm. plate, the sparking voltages as measured might be assumed to be independent of the diameter of the disk for spacings smaller than 25 cm., which was the upper limit contemplated in the investigation. The small disk, 50 cm., was a cast iron plate with the surface carefully scraped. The larger circular plane, 150 cm., was made of galvanized sheet iron with a ¾-in. (2-cm.) lead tubing soldered all around the edge.

Three pairs of cross-cylinders were used: one pair with 25-cm. in diameter being 48 in. (122 cm.) long excluding the hemispherical ends, and the other two pairs, both 5 in. (12.7 cm.) in diameter, being in two different lengths, namely, 24 in. (61 cm.) and 48 in. (122 cm.), respectively. They were supported horizontally at the ends at about four feet (120 cm.) from ground.

The method of voltage measurement was by comparison with a pair of standard 25-cm. spheres, the sparking curves being those given by the A. I. E. E. standards. Two transformers, both having the center of the high voltage winding grounded, were first calibrated against the 25-cm. sphere-gap to determine their ratios of transformation. Knowing these, the sparking voltages on unequal spheres and cross-

*For mathematical appendixes, see original paper.

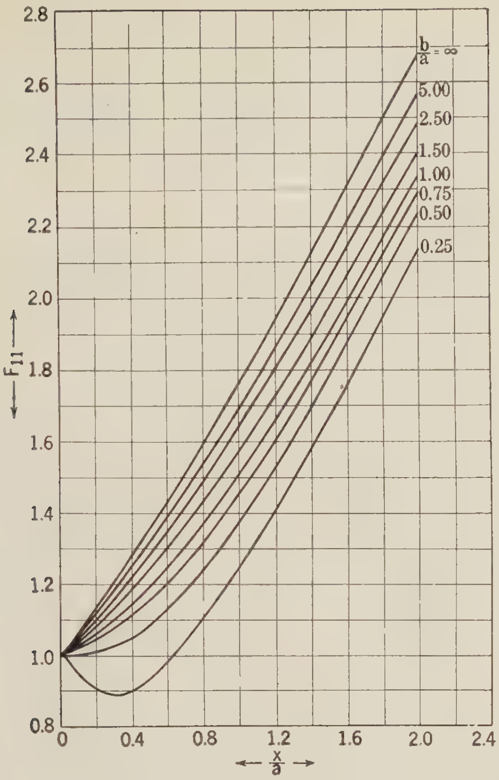

FIG. 1—COEFFICIENT OF GRADIENT FOR TWO SPHERES.

VALUES OF $F_{11}\left(\frac{x}{a}, \frac{b}{a}\right)$

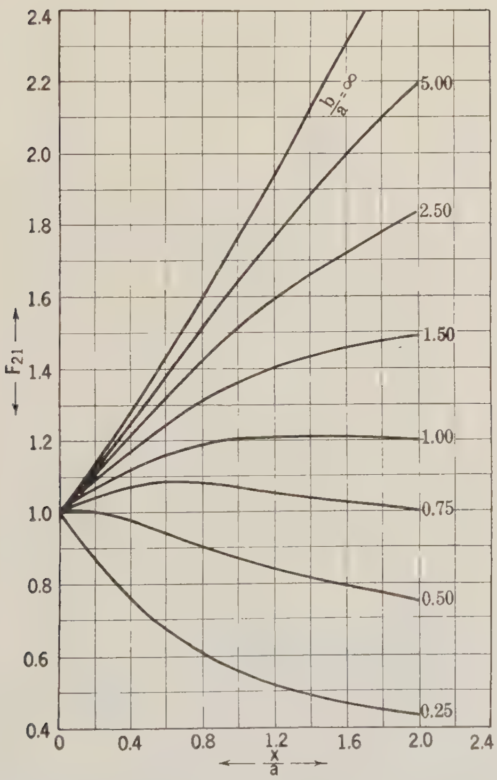

FIG. 2—COEFFICIENT OF GRADIENT FOR TWO SPHERES.

VALUES OF $F_{21}\left(\frac{x}{a}, \frac{b}{a}\right)$

cylinders were determined from the readings on the low voltage side of the transformer. The voltage ranges of the transformers were approximately 150 kv. between terminals for the smaller unit and either 250 kv. or 500 kv. between terminals for the larger unit, according to whether the low voltage side was connected

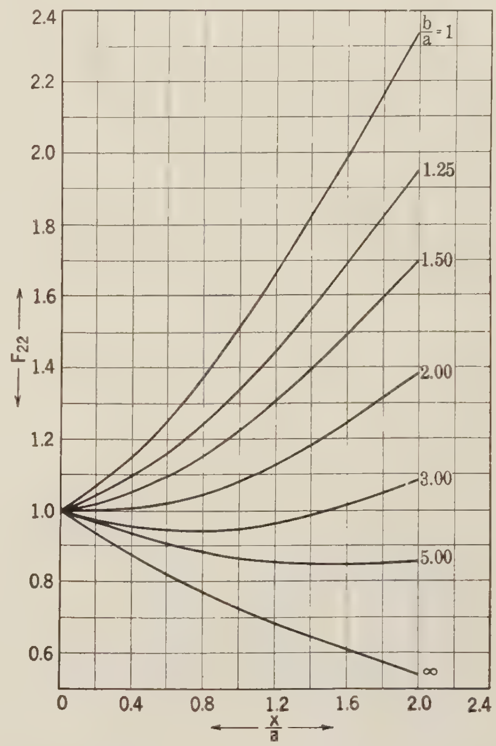

FIG. 3—COEFFICIENT OF GRADIENT FOR TWO SPHERES.

VALUE OF $F_{22}\left(\frac{x}{a}, \frac{b}{a}\right)$

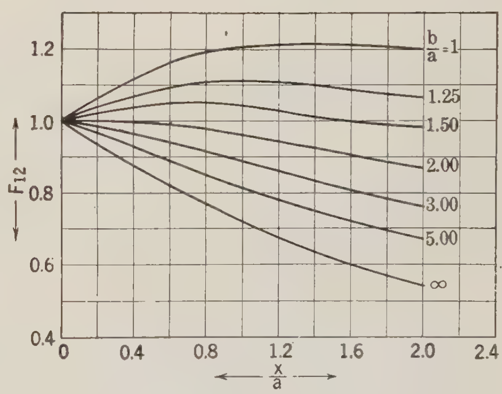

FIG. 4—COEFFICIENT OF GRADIENT FOR TWO SPHERES.

VALUES OF $F_{12}\left(\frac{x}{a}, \frac{b}{a}\right)$

in series or in parallel. The wave shape of the low voltage supply was very nearly sinusoidal. The frequency was 60 cycles.

In all of the determinations, the atmospheric density was corrected for. The correction factor was taken to be simply $3.92\,B/(273 + t)$ to reduce all observations to the standard condition of 76 cm. Hg and 25 deg. cent.,

B being the barometric reading in cm. Hg and t the temperature in degrees centigrade.

Experimental Data and Results. In the following tables, the coefficients of gradient have not been entered, their values being interpolated from the curves constructed from the tables of values already given, Figs. 1, 2, 3, 4. Calculations for the gradients were made only for cases in which the spacing was under twice the radius of the smaller sphere, as beyond this spacing there was good reason to suspect the formation of corona before a spark-over so that similar computations would become meaningless.

Each value is the average of five consecutive readings. Unless otherwise indicated, deviation from this average is small and negligible.

The symbols at the head of each column are:

a and b = radii of spheres, in cm.,

X = spacing between the spheres, in cm.,

V = sparking voltage when both spheres are insulated and are at equal and opposite potentials, in kv. eff.,

V_1 = sparking voltage when small sphere is insulated and the large one grounded, in kv. eff.,

V_2 = sparking voltage when large sphere is insulated and the small one grounded, in kv. eff.,

$G_1 = \sqrt{2}\, V F_1/X$; $G_{11} = \sqrt{2}\, V_1 F_{11}/X$; and $G_{21} = \sqrt{2}\, V_2 F_{21}/X$ are the maximum gradients at the surface of the small sphere corresponding to the three arrangements, in crest kv. per cm.,

$G_2 = \sqrt{2}\, V F_1/X$; $G_{12} = \sqrt{2}\, V_1 F_{12}/X$; and $G_{22} = \sqrt{2}\, V_2 F_{22}/X$ are the corresponding maximum gradients at the large sphere, in crest kv. per cm.

Summary of Results. Part of the above data has been plotted into several sets of characteristic curves. From these (Figs. 5, 6, 7, 8) the following points may be inferred:

1. Unstable Part of the Curves. There is a part in each sparking curve where the sparking voltage is not definite. These parts have been shown as dotted lines. The irregularities at these portions are presumably due to the formation of excessive corona and begin at a separation somewhere around three or four times the diameter of the smaller sphere.

TABLE IV

COEFFICIENTS OF GRADIENT FOR CROSS-CYLINDERS

Both Electrodes Insulated

X = spacing; a = radius of cylinder

X/a	F	X/a	F
0.0	1.00	1.6	1.23
0.2	1.01	2.0	1.29
0.5	1.06	2.4	1.35
0.8	1.10	2.8	1.41
1.2	1.17	3.0	1.44

2. General Character of Curves of Series I, Both Spheres Insulated, and Series II, Small Sphere Insulated. These two series as shown by Figs. 5 and 6, show that the more nearly equal are the diameters of the spheres the higher is the sparking curve. Thus the highest curve is the one for equal spheres as interpolated from the data of the A. I. E. E. standards while the lowest curve is the one between a sphere and a plane.

3. General Character of Curves of Series III, Large

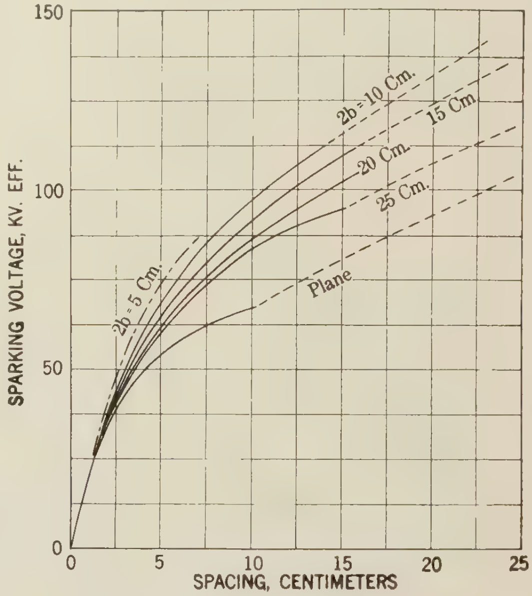

FIG. 5—SPARKING VOLTAGES V BETWEEN UNEQUAL SPHERES

Diameter of small sphere = 5.05 cm.
Diameter of large sphere = $2b$, as indicated
Both spheres insulated

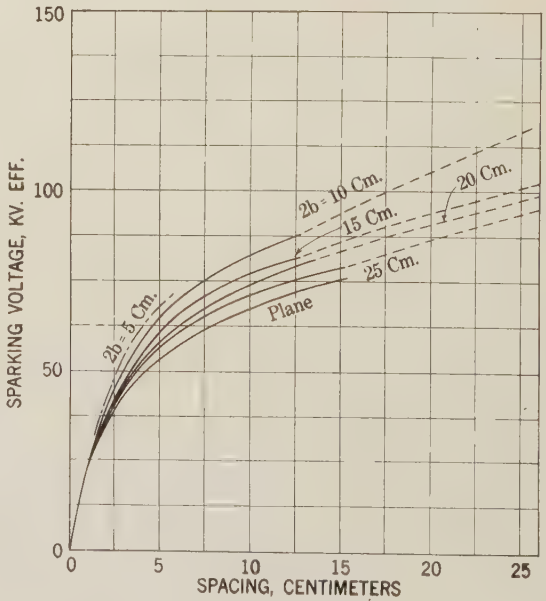

FIG. 6—SPARKING VOLTAGES V_1 BETWEEN UNEQUAL SPHERES

Diameter of small sphere = 5.05 cm.
Diameter of large sphere = $2b$, as indicated
Small sphere insulated; large one grounded

Sphere Insulated and Small One Grounded. The same conclusions cannot be reached in this case as in the previous two cases, Fig. 7. When the diameters of the spheres do not differ greatly, the sparking curve bends over much more than the corresponding curves in the

other two series. A probable reason for this will be given when the sparking gradients are studied. It will also be seen that the sparking curve between a plane and a sphere is again lowest.

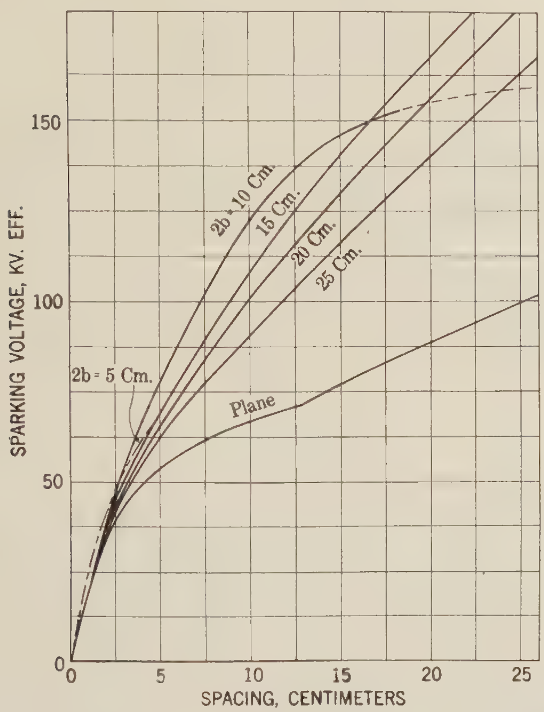

FIG. 7—SPARKING VOLTAGES V_2 BETWEEN UNEQUAL SPHERES

Diameter of small sphere = 5.05 cm.
Diameter of large sphere = 2 b, as indicated
Small sphere grounded; large one insulated

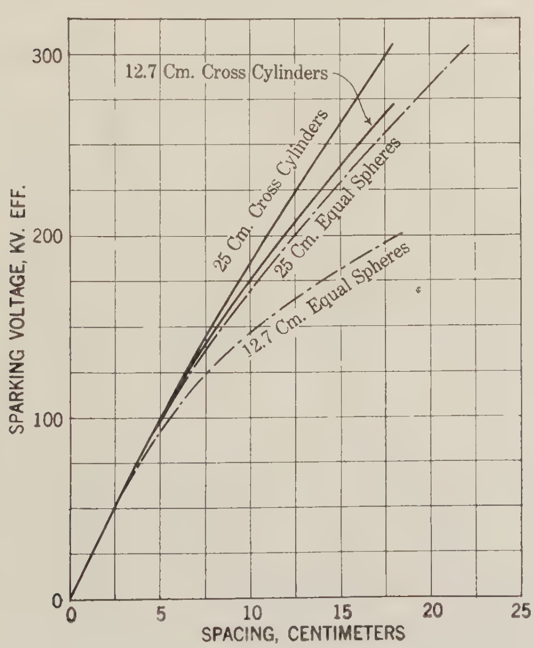

FIG. 8—SPARKING VOLTAGES BETWEEN EQUAL SPHERES AND BETWEEN EQUAL CROSS-CYLINDERS

Both electrodesinsulated

4. Sparking Gradients for Series I. From the tables, it is seen that the sparking gradients G_1 at the smaller sphere are very nearly constant for a given size of the smaller sphere within the range of the spacings investigated. The general relation is: *the smaller the radius, the higher the sparking gradient.*

5. Sparking Gradients for Series II. The values for G_{11}, *i. e.*, when the smaller sphere is insulated, will be

TABLE V

UNEQUAL SPHERES

$2a = 5.05$ cm.; $2b = 10.0$ cm.; $b/a = 1.98$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{21}	G_{22}
2.03	38.5	39.8	40.6	38.1	40.6	38.9	27.0	27.0	29.5
3.05	51.0	50.7	55.3	38.8	41.5	39.0	24.4	22.0	29.0
4.06	61.0	58.6	67.8	39.4	42.7	38.0	22.7	18.4	29.3
5.08	69.4	64.5	78.5	39.9	43.8	36.7	21.8	15.6	30.2
6.10†	76.2	71.6	89.0						
7.61	85.5	77.1	104						
9.65	95.8	82.0	121						
12.70	107	88.1	138						
17.75	125*	101*	152						
22.85	141*	108*	156*						

†From this point on, the gradient was not calculated on account of the formation of corona.

*Individual readings varied considerably from the average value here given.

TABLE VI

UNEQUAL SPHERES

$2a = 5.05$ cm.; $2b = 20.0$ cm.; $b/a = 4.00$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	36.7	36.8	37.3	38.7	39.2	38.7	22.4	22.4	23.2
3.05	47.2	46.4	48.2	39.0	39.7	38.3	18.5	17.4	19.5
4.06	55.4	53.3	58.0	39.4	40.4	38.7	15.9	13.9	17.8
5.08	62.0	59.0	65.8	39.8	41.5	38.3	14.2	12.6	17.18
6.60†	70.5	64.7	78.3						
7.62	76.5	70.1	84.4						
9.65	85.5	75.0	98.1						
12.70	94.8	80.3	118						
17.78	124	88.3	145						
22.86	134*	99.0*	171						

TABLE VII

UNEQUAL SPHERES

$2a = 5.05$ cm.; $2b = \infty$; $b/a = \infty$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	34.8	35.1	35.1	38.8	39.2	39.1	18.6	18.8	18.7
3.05	43.0	43.3	43.3	38.7	39.0	39.0	13.5	13.7	13.7
4.06	49.0	49.4	49.2	39.2	39.4	39.2	10.3	10.4	10.3
5.08	54.3	53.8	54.3	40.8	39.9	40.3	8.22	8.10	8.15
6.60†	60.0	59.4	60.0						
7.62	62.5	61.6	62.3						
10.16	67.2	66.7	67.5						
12.70	75*	72.4	71.3						
17.78	85*	81.5	85.2						
22.86	100*	93*	95.1						

TABLE VIII

UNEQUAL SPHERES

$2a = 10.0$ cm.; $2b = 15.0$ cm.; $b/a = 1.50$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	41.7	41.8	41.8	34.4	34.7	34.2	30.3	30.2	30.6
3.05	59.4	58.5	59.4	35.1	35.3	34.5	29.4	28.4	30.1
4.57	82.6	79.0	84.0	36.3	36.7	34.8	28.5	26.0	30.6
6.60	104	97.5	112	36.1	37.8	33.9	26.4	21.1	32.2
8.64	122	110	135	36.0	38.5	32.2	25.3	17.9	34.0
10.16	132	118	151	35.8	39.2	31.3	24.6	16.0	35.7
12.70†	148	128	168						
15.24	163	145	178						
20.32	187	152*	194						
25.40	206	145*	203						

seen to increase somewhat with the spacing. This increase seems to be greater as the ratio of the radii, b/a, is more nearly unity. Thus for equal spheres, this

increase will be found to be greatest and for a plane and a sphere, it is almost entirely negligible.

6. Influence of G_2 and G_{12}. For the two series above discussed, the influence of the gradients at the surface of the larger sphere, *i. e.*, of G_2 and G_{12}, seems to be negligible since they vary between wide limits. It is probable that they do not have any primary effect in causing the sparking, which, as already pointed out,

TABLE IX

UNEQUAL SPHERES

$2a = 10.0$ cm.; $2b = 25.0$ cm.; $b/a = 2.50$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	42.0	41.8	41.8	35.6	35.2	35.2	28.3	28.6	28.3
3.05	58.3	57.4	57.8	36.1	36.0	35.3	26.0	25.2	26.1
4.57	77.0	75.1	77.6	36.2	36.3	35.2	22.6	21.2	23.7
6.60	96.5	92.1	101	36.2	37.1	35.2	19.7	17.0	22.5
8.64	112	104	121	36.4	37.7	34.8	17.9	14.1	22.4
10.16	122	112	135	35.7	38.5	34.2	17.1	12.5	22.5
12.70†	137	122	157						
14.73	148	..	173						
18.29	..	136							
21.34	173	..							
25.40	184	142							

TABLE X

UNEQUAL SPHERES

$2a = 10.0$ cm.; $2b = \infty$; $b/a = \infty$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	39.9	39.5	39.5	35.7	35.2	35.2	24.2	24.0	24.0
3.05	53.1	53.2	52.9	35.4	35.5	35.2	20.2	19.6	20.0
4.57	68.8	68.0	68.5	35.7	35.2	35.8	15.8	15.6	15.6
6.60	82.6	82.2	82.0	35.9	35.7	35.6	11.7	11.6	11.6
8.64	92.4	91.7	92.5	36.2	36.0	36.2	8.89	8.83	8.90
10.16	99.6	99.5	99.5	37.0	36.9	36.9	7.55	7.55	7.55
12.70†	108	107	108						
15.75	119*	116*	117						
19.30	122*	134*	128						
25.40	133*	138*	142						

TABLE XI

UNEQUAL SPHERES

$2a = 15.0$ cm.; $2b = 20.2$ cm.; $b/a = 1.345$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	42.5	42.4	42.5	33.0	32.9	32.9	31.8	31.8	31.8
3.05	60.7	60.5	60.6	33.0	33.2	32.7	30.0	29.7	30.2
4.57	85.7	84.1	86.0	33.4	33.7	32.7	29.2	27.8	30.2
6.60	113	108	117	33.6	34.3	32.5	28.2	25.1	31.3
8.64	137	129	146	34.0	35.3	32.2	27.4	23.2	32.6
10.67	157	143	171	34.0	35.9	31.2	26.7	20.2	34.1
13.71	182	160	198	34.1	36.8	28.5	26.1	17.1	35.7
15.24	191	..		34.8	..		25.8	..	
16.76†	..	172							
19.30	218	182*							
22.86	..	199*							
25.40	248	205*							

TABLE XII

UNEQUAL SPHERES

$2a = 15.0$ cm.; $2b = \infty$; $b/a = \infty$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	40.5	41.1	41.8	33.5	34.0	34.5	25.7	26.1	26.5
3.05	56.9	57.0	56.5	33.8	34.0	33.6	22.9	23.0	22.8
4.57	75.9	75.5	74.8	34.0	33.7	33.4	19.1	19.7	18.8
6.60	94.7	94.6	94.5	33.7	33.8	33.7	15.2	15.2	15.2
8.64	109.	109	110	34.1	34.1	34.3	12.2	12.2	12.4
10.67	120	121	122	34.2	34.2	34.7	10.0	10.1	10.2
13.71	135	133	137	35.0	34.4	36.0	7.85	7.72	7.94
16.76†	146	144	149						
19.30	155	153	160						
22.86	165	166*	172						
25.40	170	171*	180						

TABLE XIII

UNEQUAL SPHERES

$2a = 20.2$ cm.; $2b = \infty$; $b/a = \infty$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	41.1	40.0	41.5	32.4	31.6	32.7	26.7	26.8	26.9
3.05	59.0	58.1	58.3	32.9	31.8	32.5	24.6	24.3	24.4
4.57	80.7	80.1	79.9	32.8	32.6	32.5	21.5	21.3	21.2
6.60	104	104	103	33.0	32.8	32.5	18.1	17.9	17.8
8.64	123	122	122	33.0	32.8	32.8	15.2	15.1	15.2
10.67	137	136	138	32.8	32.8	33.0	12.9	12.8	13.0
13.21	153	151	154	33.3	32.8	33.4	10.8	10.8	10.9
16.25	168	165	172	33.6	33.0	34.4	8.83	8.65	9.05
20.32†	183	180	190						
25.40	196	194	214						

TABLE XIV

UNEQUAL SPHERES

$2a = 25.0$ cm.; $2b = \infty$; $b/a = \infty$

X	V	V_1	V_2	G_1	G_{11}	G_{21}	G_2	G_{12}	G_{22}
2.03	41.0	41.0	41.6	31.5	31.5	31.5	27.0	27.0	27.1
3.05	58.6	58.4	58.2	31.6	31.4	31.4	25.1	25.0	24.8
4.57	82.2	81.3	81.9	31.7	31.5	31.6	22.5	22.2	22.4
6.60	107	106	108	31.4	31.4	31.6	19.0	19.0	19.4
9.15	131	133	135	31.0	31.5	31.9	15.9	16.1	16.3
11.18†	147	150	152	31.0	31.5	31.9	13.9	14.2	14.4
13.71	165	168	172	31.3	31.7	32.6	12.0	12.2	12.5
17.27	186	188	195	31.6	32.1	33.3	9.83	10.0	10.4
21.34	205			32.3			8.00		
25.40	221			32.8			6.72		

TABLE XV (A)

CROSS-CYLINDERS

Diameter = 12.7 cm.; net length = 61 cm.

Both Electrodes Insulated

X	V	G	X	V	G
2.23	45.7	30.3	7.14	134	30.4
3.17	64.3	30.1	9.65	169	30.0
4.32	88.5	30.5	11.15	188	29.6
5.86	113	30.4	12.50	192*	....

*Sparking across the ends; not reliable.

TABLE XV (B)

CROSS-CYLINDERS

Diameter = 12.7 cm.; net length = 122 cm.

Both Electrodes Insulated

X	V	G	X	V	G
2.74	55.8	30.3	9.75	171	30.3
3.83	77.7	30.3	11.86	195	30.1
4.95	96.7	30.5	14.00	221	29.7
6.43	122	30.7	15.40	242	30.2
7.95	145	30.5	16.50	255	30.3

TABLE XVI

CROSS-CYLINDERS

Diameter = 25.0 cm.; net length = 122 cm.

Both Electrodes Insulated

X	V	G	X	V	G
2.62	54.5	29.7	9.60	179	28.5
3.81	77.7	29.1	12.38	221	28.2
5.03	99.5	29.4	14.40	245	27.8
7.95	151	28.5	17.60	291*	....

*Sparking across the ends; not reliable.

seems to be mainly governed by the gradients G_1 and G_{11} at the smaller sphere.

7. Sparking Gradients for Series III. For the third series, namely, that in which the smaller sphere was grounded with the high voltage applied to the large sphere, the sparking gradient G_{21} at the surface of the smaller sphere sometimes increases and sometimes decreases with the spacing while the values of G_{22}, *i. e.*, the gradient at the larger sphere, are not always smaller than G_{21}. In fact, for the cases in which the sparking curves in the third series bend over and intersect the others as noted in (3) above, the gradient G_{22} increases and finally becomes larger than G_{21}; see Tables VIII and XI. In these cases it is probable that the law of sparking should be formulated to take account of the influence of both G_{22} and G_{21}. This is a probable explanation why the curves in this series bend over much more than the corresponding curves of the other two series.

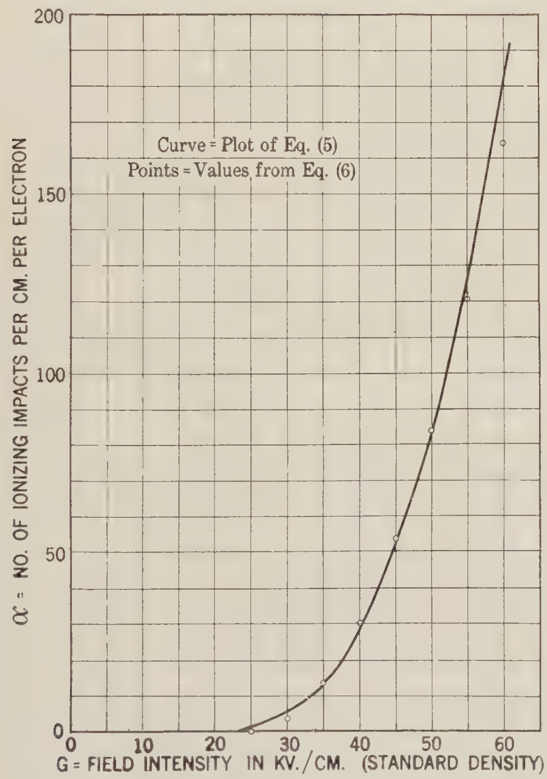

Fig. 9

8. Comparison of Curves for the Three Series. When the same pair of spheres is used, it will be seen that the sparking curve is highest when the smaller sphere is grounded and lowest when it is insulated, with the case when both spheres are insulated and are at equal and opposite potentials falling in between the two. For the arrangement when one sphere has infinite radius, *i. e.*, a plane, all three curves are practically the same.

9. Data on Cross-Cylinders. The general relation that the smaller the radius, the higher the sparking gradient, has been found to be also true in the case of cross-cylinders. When the electrodes are at equal and opposite potentials, this gradient seems to be a constant for the spacings considered. As no mathematical calculation has been made to determine the sparking gradient when one cylinder is grounded, nothing can be inferred about this arrangement. Measurements of the sparking voltages in this latter arrangement showed, however, that the sparking voltages were not far different from those determined for the former case of both insulated electrodes. Because of the flux distribution, it will be noted that the sparking curve for cross-cylinders lies higher than the corresponding curve for spheres with the same radius, Fig. 8. It should also be noted, however, that the sparking gradient in the case of cross-cylinders is *smaller* than the corresponding value for equal spheres having the same radius.

From the data on the two lengths of the 12.7-cm. cylinders, it will be seen that when the spacing was below one-sixth of the net length of the cylinder, no appreciable difference in the sparking voltage was observed by using either pair of electrodes.

Part II

Theoretical Considerations

Before proceeding to a discussion of the Davis theory of the corona, from which it will be shown how to derive the relation between the sparking gradient and the radius of the sphere, it would be advisable to give a brief account of Peek's theory of the sphere-gap so as to afford a ready comparison of the two. Peek[19] assumes that air has a constant dielectric strength G_0. But to cause rupture, energy as well as gradient is necessary. Thus corona or sparking does not occur when the gradient at the surface of the electrode equals G_0, because energy has not yet been supplied sufficiently. It is only after the gradient at a certain distance away from the surface of the electrode equals G_0 and hence that at the electrode *exceeds* G_0, that the energy supplied is great enough to cause a rupture. Thus due to curvature of the electrodes, the sparking gradient at the electrode with the radius a should satisfy a relation:

$$G_a = G_0\,(1 + A/\sqrt{a}) \qquad (1)$$

in which A is a constant, G_0 the constant dielectric strength of air and a the radius. From his results on concentric cylinders, parallel wires and spheres, Peek finds that the values for G_0 vary somewhat for the three arrangements. He attributes this variation to the unbalancing of the field and claims that the dielectric strength of air is probably given by the value 31 kv. per cm. as obtained from the determinations on concentric cylinders where the field distribution is the same on all sides. In the case of parallel wires, there is some unbalancing so that G_0 becomes less, being only 29.8 kv. per cm., while for spheres, the unbalancing is greatest, in consequence of which the value of G_0 is also lowest, being only 27.2 kv. per cm.

Besides this difficulty and the rather indefinite

magnitude of the rupturing energy required by Peek's theory, it is also necessary to account for the variation of the sparking gradients in the cases when one of the spheres is grounded. Although arguments have been advanced to explain this variation, they are not at all convincing[20]. As Bergen Davis has demonstrated how the theory of ionization by collision can be applied to the corona formation around cylindrical conductors, it appears best to extend this to the case of the sphere-gap since our present knowledge and confidence in the electron theory is far greater than at the time of the deductions of Davis.

According to this theory[21]: At atmospheric conditions, ionization of the gas molecules is primarily due to the collisions with electrons. The ionizations caused by positive ions and photoelectric effects are very small and may be neglected. This ionization is cumulative and the formation of corona or a spark is governed by the condition:

$$\log \frac{n\,a^2}{n_0\,y_0^{\,2}} = K = \int_a^{y_0} \alpha\,d\,y \qquad (1)$$

in which,

n = density of electron at surface of sphere,

n_0 = density of electron at a distance $y_0 - a$ from surface, at which ionization by collision is appreciable

a = radius of sphere and

α = no. of electrons produced by one electron in going through a distance of 1 cm. under a gradient of G kv./cm.

To integrate (1), it is necessary to express α in terms of y. This can be done if the relation between α and G is known, because, as will be shown in the Appendix, for small distances away from the surface of the sphere, the gradient G varies inversely as the distance from the center of the sphere. Thus, if G_0 is the gradient at the point on the line of centers whose distance from the center of the sphere is y_0, and G_a is the gradient at the surface of the sphere with radius a, then $G_a = G_0\,y_0^2/a^2$; and, in general, if y is the distance of a point on the line of centers from the center of the sphere, the gradient at y is $G = G_0\,y_0^2/y^2 = G_a\,a^2/y^2$, if $y - a$ is small.

Regarding the relation between α and G, Bergen Davis has developed a formula by considering the energy required for ionization. In terms of the ionization potential v and the mean free path L of the electrons, this relation takes the form:

$$\alpha = \frac{1}{L}\,e^{-\frac{v}{GL}} + \frac{v}{G\,L^2}\,E\,i\left(-\frac{v}{G\,L}\right) \qquad (2)$$

where $E\,i$ is the exponential integral. Using the value $v = 10.2$ volts as found by Bishop[23] and taking L as $4\sqrt{2}$ times the mean free path of the molecules in air[24], *i. e.*, $4\sqrt{2} \times 9.83 \times 10^{-6} = 5.55 \times 10^{-5}$ cm. for the free electrons in air, values of α can be calculated for different G's. A calculation of this sort has been made using the tables of Jahnke and Emde[25] for the values of the exponential integral. For values of G covered by the investigation, it is found that an empirical quadratic relation represents the theoretical relation (2) very satisfactory. This relation is:

$$\alpha = C\,(G - G_0)^2 = 0.134\,(G - 25)^2 \qquad (3)$$

where G is in kv. per cm. The agreement between (3) and (2) is well shown by the accompanying curve, Fig. 9. As relation (2) can not be used for integration in finite terms, relation (3) will be used. Also as $G = G_0\,y_0^2/y^2$, (3) can be written as

$$\alpha = C\,G_0^{\,2}\left[\frac{y_0^{\,2}}{y^2} - 1\right]^2 \qquad (4)$$

Substituting this into (1) and performing the indicated integration, it is found that

$$\log \frac{n\,a^2}{n_0\,y_0^{\,2}} = K = 83.7\,a\left[\frac{8}{3}\sqrt{\frac{G_a}{G_0}} + \frac{1}{3}\left(\frac{G_a}{G_0}\right)^2 - \frac{2\,G_a}{G_0} - 1\right] \qquad (5)$$

In this form, the equation still contains a quantity n_0, of which nothing is known. If it is assumed for the present that the total number of electrons crossing any spherical surface completely enclosing one of the electrodes remains always the same, then the density of electrons on any such spherical surface will vary inversely as the square of the radius. In the equation above given, it is then permissible to put the quantity K equal to a constant. Granting such an assumption, the theory then leads to the result that the sparking gradient is a function of the radius of the smaller sphere only.

In his theory of the corona, Davis had to do with a similar quantity which he assumed to be constant and equal to 6 for concentric cylinders and to 4.3 for parallel wires. If K is taken as 4 for the sphere-gap, it will be found that equation (5) agrees fairly well with the data given by the Institute standards and those of the present investigation when only the case of symmetrical application of voltage is considered, *i. e.*, when both spheres are insulated and are at equal and opposite potentials. In fact, changing the square-root function to a quadratic function by the following empirical relation, which will be found to be accurate to within half of a per cent for values of X lying between 1 and 2, namely,

$$\sqrt{X} \simeq -0.071\,X^2 + 0.630\,X + 0.441 \qquad (6)$$

the relation (8) can be put in the form:

$$G_a = \left(1.105 + \frac{0.288\,\sqrt{K}}{\sqrt{a}}\right) G_0 \qquad (7)$$

With $K = 4$ and G_0 as 25, (7) at once becomes

$$G_a = 27.6\left(1 + \frac{0.52}{\sqrt{a}}\right) \qquad (8)$$

whose similarity to the relation of Peek, *viz.*,

$$G_a = 27.2\,(1 + 0.54/\sqrt{a})$$

or to that of Russell, *viz.*,

$$G_a = 27.4\,(1 + 0.515/\sqrt{a})$$

is very remarkable and striking.

Concluding Remarks

It should be noted that in the above work, the value of K has been assumed to be constant. It is the simplest assumption. On closer examination, it will be seen that n_0 cannot be as simply related to y_0 as an inverse square relation. For instance, as shown by Davis in his theory, when the spacing is very short, the electrons moving outward will be taken up and neutralized by the other sphere and the process of cumulative multiplication at the surface of the sphere M will not take place as readily. In fact, for short spacings, $n_0\,y_0^2$ decreases as the spacing (hence K increases) because of the disappearance of a number of electrons at the surface of the other electrode. It is therefore possible to explain the rapid increase of the sparking gradient as the spacing is decreased to very short values. Thus the simple relation of Peek and Russell, which may be derived from the theory of Davis, appears to be merely an approximation giving good results only for special cases, namely, when both spheres are insulated and are at equal and opposite potentials, in which case it is permissible to assume K to be a constant independent of the arrangement. As for the cases in which one of the spheres is grounded, the value of K is probably influenced both by the gradient at the surface of the larger sphere and the spacing between them, so that it is no longer a constant independent of the arrangement. On this account, it is thus also possible to explain why *the constancy of the sparking gradient is not of general validity.* A point of interest to note is that the smaller value of G_0, Peek's notation, for spheres, *viz.*, the value 27.6 as against 31 for concentric cylinders or 29.8 for parallel wires, is a natural consequence of the theory and does not require any explanation such as that advanced by Peek.

The writer is under great obligation to Prof. A. Wilmer Duff and Prof. Harold B. Smith for suggestions made and for facilities and encouragement in the preparation of the paper.

Abridgment of

Current Collection from an Overhead Contact System Applied to Railroad Operation

BY S. M. VIELE[1]

Non-member

Synopsis—*This paper discusses, from a non-mathematical standpoint, certain factors which should enter into the design of an overhead contact system on an electrified railroad. It emphasizes desirable features, mechanical and structural, and indicates practical limits which conditions will permit in the attainment of these features.*

Tests made by the Pennsylvania Railroad with slow-motion photography are outlined. These tests were made to determine operating conditions of the catenary construction with two different types of supporting attachments, over both curved and tangent track. Deflections and oscillations were studied in order to bring out the most productive sources for future study and improvement of the design in respect both to elimination of wear and to maintenance of uniformly good current collecting qualities.

The use of low potentials on a contact system permits the installation of the contact conductor in such a position that, although within relatively easy access to the public, in general, it is not an undue hazard to them. The use of higher potentials on such systems has carried with it increased hazard, which has necessitated the isolation of this conductor at distances which materially reduce the hazards of accidental contact.

Isolation has usually taken the form of an overhead contact conductor along which a shoe or wheel is carried by the locomotive or car. The distance from the rail to the contact wire varies through relatively wide limits due to the exigencies of the conditions to be met along practically all railroad rights-of-way. Overhead bridges, tunnels and other obstructions require construction at heights which will permit little more than actual clearance for the rolling stock, whereas reduction of hazard to trainmen and the public generally requires a greater clearance than that usually obtainable through obstructed territory.

The height of a multiple-unit car, such as is used in our suburban service, to the crown of the roof is 13 ft., 0 in. (3.96 m.) The height of an electric locomotive of L 5 class is 13 ft., 5 in. (4.09 m.). These dimensions have resulted in our setting a minimum trolley wire height of 15 ft., 3 in. (4.65 m.) in completely electrified territory where steam locomotives are not permitted to move. This minimum trolley height is never used except where the conditions necessitate. It represents conditions in tunnels and is occasionally approximated at overhead bridges.

The installation of a contact system at such an

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elevation would make approach to the roof of cars or locomotives very dangerous and would not represent an operative condition if used, except in very limited stretches.

In case operation should require an employee on top of the rolling stock for minor repair work, the height of trolley should be 22 ft. (6.71 m.) as this is the minimum height with which it is at all feasible to make even minor repairs. This includes an allowance of about one ft. (0.30 m.) for the increased sag under hot weather conditions. Such a dimension for trolley height has been adopted for suburban territory. It is not an ample clearance but some work can be done if proper care is taken. At the same time, my own experience does not permit me to say that it is a position of mental comfort. Two feet more, or a total contact height of 24 ft. (7.31 m.) is, from a clearance standpoint, a very much better proposition. This additional two-ft. (0.61 m.) clearance above a minimum of 22 ft. (6.71 m.) is very hard to obtain and in some cases almost impossible in urban districts, owing to the requirements placed for city grades, adjacent property conditions, etc. In open country, where there are relatively few overhead bridges, the 24 ft. (7.31 m.) can be obtained and such a standard set.

The distance from rail to contact wire will vary from about 15 ft. (4.57 m.) to approximately 25 ft. (7.62 m.). This variation requires that the device which carries the actual contact member and bridges the space between the locomotive or car roof and the contact wire shall be capable of operation at varying heights over a range of some 10 ft. (3.05 m.). Its operating range should permit of its minimum height position being about three in. (0.08 m.) below the minimum operating height position and it should be capable of extending some 6 in. to 12 in. (0.15 m. to 0.30 m.) beyond its highest operating position.

FIG. 1—VIEW OF STANDARD CONSTRUCTION ON CURVED TRACK

Steadying against side-sway on standard tangent track is accomplished in a similar manner

Pantographs, carrying collecting shoes, have been exclusively used by the Pennsylvania Railroad for this purpose, for high voltage service. We have two broad classifications for pantographs, depending upon the equipment to which they are to be applied, *i. e.*, locomotives and multiple-unit cars. The multiple-unit pantograph is a single shoe device of relatively light construction, whereas the locomotive pantograph is heavier and carries two shoes. The weights of these equipments are of the following order:

FIG. 2—VIEW OF SPECIAL CONSTRUCTION ON TANGENT TRACK

Steadying against side-sway on special curved track is accomplished in a similar manner

	Pounds		
	Gross	*"Live"	Shoe
Locomotive.......	1400 (635 kg.)	243 (110 kg.)	33 (15 kg.)
Multiple unit......	710 (322 kg.)	100 (45 kg.)	14 (6.3 kg.)

*Shoe and extensible frame work

In both types of equipment, the "live" weight is carried by the journal of a rotative shaft at each end of the pantograph, the two shafts having connected thereto the bottom members of the pantograph movable framework, which members are held in supplementary angular relation with the base of the device by bell cranks and interconnecting links. In all operating positions, the weight of the "live" parts is eccentric to the shafts, which produces a torsional moment on the shafts which varies in amount throughout the entire operating range. This torsional moment is counterbalanced with helical springs, in tension, applied through chains operating over cam surfaces, the latter being attached to each end of each shaft.

The necessity for a small collapsed height of pantograph does not permit of a very large radius for the cams nor a large elongation of the springs and, consequently, the spring tensions are material. This spring tension is used to support the pantograph in all operating positions and to provide the force required for upward acceleration of the shoe and frame work, as well as to overcome the frictional resistance to upward movement.

Collection requires that the force of contact should be as near constant as is feasible and that the friction of vertical movement of pantograph should be relatively small. It becomes evident that this is not a simple problem when it is considered that the spring tension on a multiple-unit pantograph for operation on trolleys at 22-ft. (6.71 m.) elevation is 460 lb. (208.6 kg.) for the minimum operating height and 150 lb. (68.0 kg.) for the maximum operating height, in each of four springs, and that the weight of the moving members

Fig. 3—Enlargement From Slow-Motion Picture

This shows the locomotive pantograh shoe parting contact at the trailing end of a wire splice

is of the order of 100 lb., (45.4 kg.) the latter being variably applied. A pantograph operated vertically, on a stationary block, exerts 18 lb. (8.2 kg.) of upward force under slow motion conditions, with a total variation of force of about 10 per cent. Downward motion produces approximately 10 per cent additional variation.

The above figures are based upon favorable conditions. If sleet accumulates on the framework, it

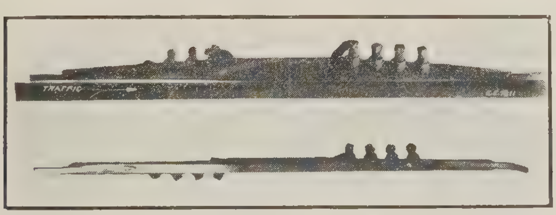

Fig. 4—Close-Up of Badly Worn Wire Splice

This picture shows the occurrence of wear at the approaching end and pitting action at the trailing end of the splice

does not take long until sufficient weight is added to overcome the 18 lb. (8.2 kg.) of upward force. Wind loads have affected the operation of some of the early designs to a sufficient extent to actually drop the mechanism.

It has been frequently asked why the upward pressure should not be increased so as to have a larger working margin. Two major limitations exist.

In case the sum of the pressures of all pantographs on a given span of contact wire approaches the weight of construction lying immediately adjacent to the contact plane, columnar instability of the overhead results. If the pressures are increased sufficiently, the contact wire will occasionally turn over, exposing the contact wire attachments to blows from the passing pantograph.

The wear on shoes and the contact wire itself is, for a non-lubricated contact, a function of the mechanical abrasive effect varying with pressure, and the pitting and burning effects caused by current flow.

The most economical pressure apparently varies with the current collected from a single shoe. As the current

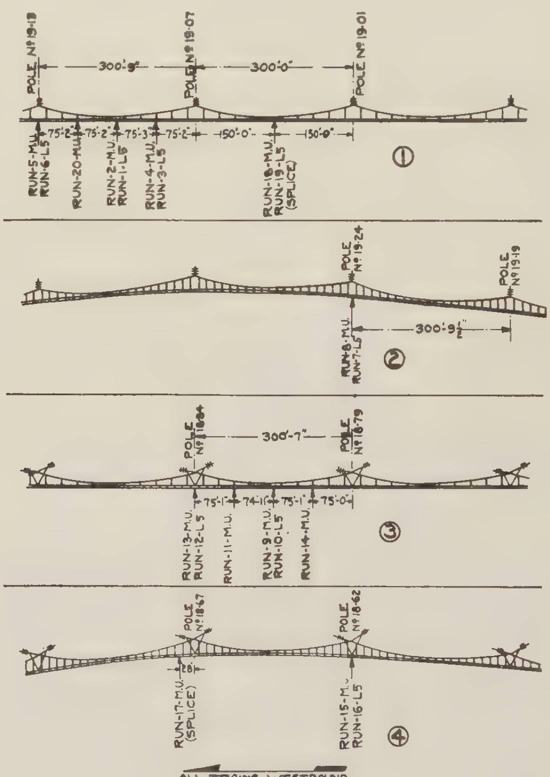

Fig. 5—Location Diagram of Slow-Motion Pictures

1. Standard tangent construction
2. Standard curve construction
3. Special tangent construction
4. Special curve construction

value decreases, lighter pressures can be advantageously used. This is fortunate, as otherwise it would be difficult to operate some four to six multiple-unit pantographs in a given span without increasing the weight of actual contact system or providing special stiffening attachments for the contact wire.

The force required for downward acceleration of the "live" parts of the pantograph is the sum of the upward thrust of the shoe plus an increased reaction to cause downward acceleration. This sum must not reach a value which will permit the turning of the contact wire. It follows that the upward acceleration forces which are permissible in the pantograph are less, by an amount necessary to produce maximum downward accelera-

tion, than those which will be sufficient, under any conditions, to cause overturning of the contact wire. It should be borne in mind that the downward accelerating forces vary with speed of traffic, gradients, changes of sag, etc., and a suitable margin must be left between these totaled upward pressures and the weight of the construction adjacent to the contact plane.

A pantograph shoe is limited in length (about four ft. (1.22 m.) transverse to the track), and if the overhead is not properly located over the track, or if the catenary is permitted to sway under wind conditions to a sufficient extent, the shoe passes to one side of the contact wire, rises to an elevation above the contact wire and practically always catches in some part of the overhead, with the result of damage to the pantograph sufficient to render it inoperative and occasionally materially damaging the overhead.

Reduction of occurrences of this nature on tangent track may be obtained by shortening the span length or by means of steadies applied at the support points. The latter is the more economical procedure. Spans may be installed with little trouble of this nature, of the order of 285 ft. (86.87 m.) in length, with proper steadies at support points, in locations exposed to wind. In protected localities, this value may be increased to about 325 ft. (99.06 m.). Without steadies, our experience would indicate that these figures should each be reduced about 100 ft. (30.48 m.).

On the assumption that the more economical construction should be used, that is, longer spans, one is immediately faced with the design of steady which will limit motion tranverse to the tracks, allow longitudinal equalization of tensions and permit as great a vertical movement of the contact member at the support points as is possible. The above represents the mechanical requirements. Electrical requirements involve the maintenance of potential across the insulators and of suitable clearances. Maintenance requires easy access with suitable working clearances, prevention of burning of the vital members of construction in case of flashover of insulators, and in case of damage, the positioning of members such as to clear pantographs in as many cases as possible.

The trolley construction used in the Broad Street-Paoli district, carrying 11,000 volts single phase, consists of a ½-in. (12.7 mm.) steel messenger, from which is suspended, by 3/16-in. by 1-in. (4.75 mm. by 25.4 mm.) straps at 30-ft. (9.14 m.) intervals, a 1/0 round copper auxiliary wire, from which, in turn, is suspended, by clips at 15-ft. (4.57 m.) intervals, a 3/0 grooved bronze contact wire. The contact and auxiliary wires lie parallel to one another in a vertical plane. The connections between these two wires "break joints" with the connecting hangers lying between the messenger and the auxiliary wire. Span lengths vary from a maximum of 325 ft. (99.06 m.) to values necessitated by conditions with an average of about 300 ft. (91.44 m.).

The suspension of the catenaries consists of a three-unit cap and pin type insulator and assembling hardware, to which the messenger is attached. This represents a pendulum length of about 24 in. (0.61 m.) applicable to the messenger. The messenger has five ft. (1.52 m.) of sag in a 300-ft. (91.44 m.) span, which

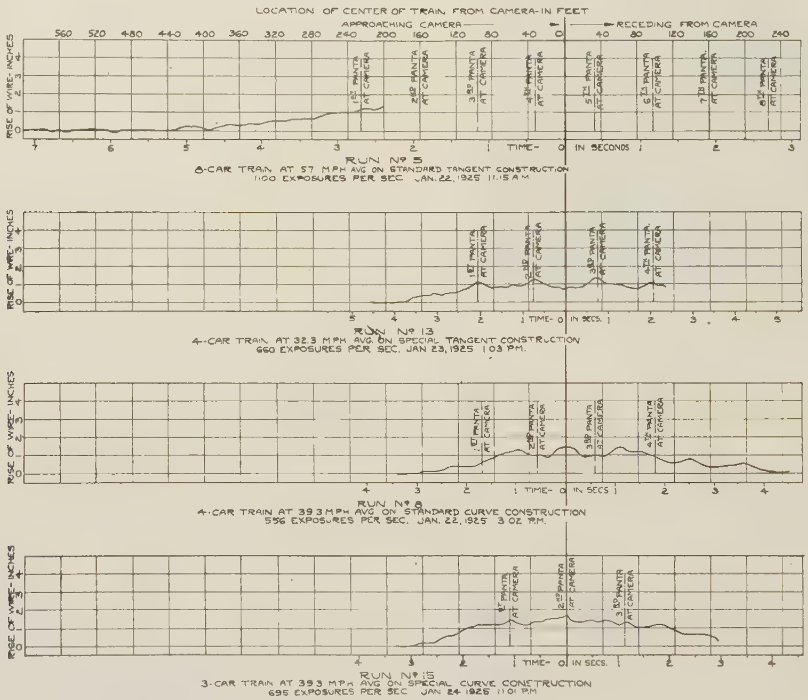

FIG. 6—UPWARD DEFLECTION OF CONTACT WIRE

Measured at support point of catenary span

construction produces a total pendulum length at the support point of approximately 7ft., 6 in. (2.29 m.).

The original design did not call for the use of steadies except at a few locations. Operation, however, has necessitated their general installation in exposed locations.

The steady design adopted consisted of a horizontal strand installed between the catenary supporting poles at an elevation six in. (0.15 m.) above the contact wire. This strand was insulated from the poles by three-unit porcelain insulators adjacent to the poles, with a sectionalizing wood stick insulator between the auxiliary

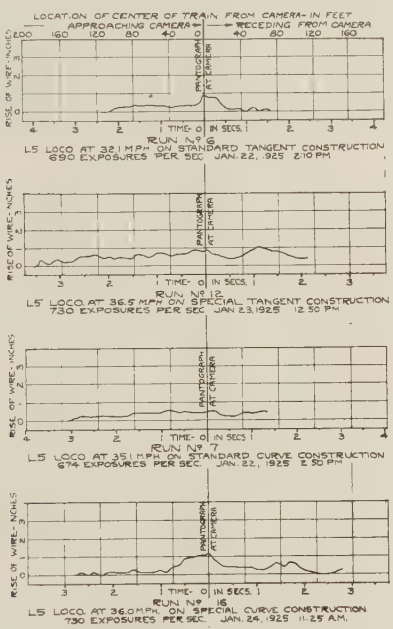

FIG. 7—UPWARD DEFLECTION OF CONTACT WIRE

Measured at support point of catenary span

wires of adjoining tracks. Attachments were made by a slack two-way jumper from this strand to the auxiliary wire. This construction reduced what may be termed "pantograph derailments" to a radical degree. The disadvantages of this design were:

a. The wood sticks used for sectionalizing the track trolleys do not have potential impressed across them except under conditions of a de-energized adjacent track, which condition usually develops their failure, if any, at the most inopportune time.

b. Small working clearances for certain repair operations.

c. Periodic cleaning, varnishing and general over hauling of the wood sticks.

d. The impassability of one or more tracks in case of steady span failure, on account of portions of steady span construction hanging down below the elevation of the contact plane.

e. Small upward deflection of the contact wire at the support point.

In the effort to improve catenary support conditions, a new form of support was laid out which, in my opinion, reduces to a material degree the disadvantages of the previously described steady.

The standard form of back guyed poles, cross catenary and body span member were used; however, instead of suspending an insulator string directly over the track for attachment of the messenger, a string was placed each side the center line of each track. Connected between these insulators is a short length of cable approximately eight ft. (2.44 m.) long, with sufficient sag in it that when drawn downward at its center, it forms the two legs of an obtuse triangle with its apex about 30 in. (0.76 m.) below the body member, this point being used for the attachment of the messenger. The ends of the insulators nearest the center line of the track have a second attachment with members running to a common point and attached to the auxiliary wire. In appearance, the construction forms a letter "V" with the auxiliary wire attached at the bottom apex and the upper ends of the legs of the "V" attached to sides of the obtuse triangle at the lower ends of the insulators. This construction fixes the position transversely of the messenger, and eliminates the pendulum length of the messenger suspension. It places all insulators between trolley and ground, thereby retaining potential across

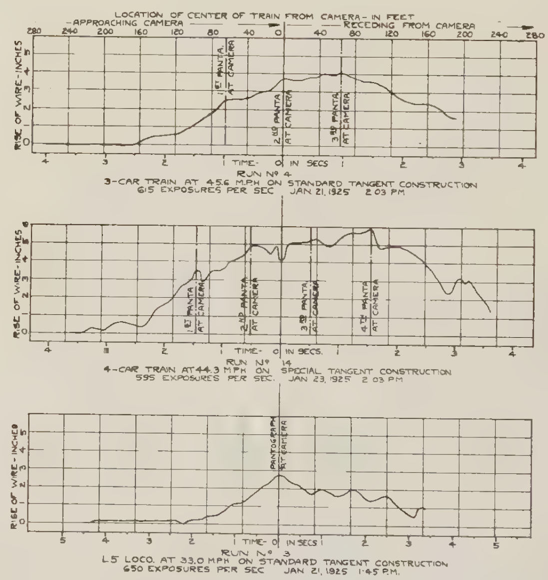

FIG. 8—UPWARD DEFLECTION OF CONTACT WIRE

Measured at entering quarter point of catenary span

them. It introduces a short section of cable between the messenger and the insulators, and consequently, an arc from a flashed insulator is removed from the messenger and taken by the messenger supporting member.

A parallel path for current supply to an arc at the insulator is provided by the secondary hanger connecting between the auxiliary wire and a point adjacent to the live end of the insulator. This, we consider, will reduce the localized annealing of the messenger under flashed insulator conditions, as there is provided a shunt path for the current flowing from the trolley and

auxiliary wires to the point of arc contact with the catenary supporting member.

The two members forming the lower "V" converging on the auxiliary wire leave the clearance between tracks as a maximum at the contact wire elevation, with the minimum clearance existing at the insulators, just below the body member.

In thinking of catenary construction, most engineers consider that contact is made with the overhead conductor in practically a uniform plane and that there is little or no upward displacement with pantograph

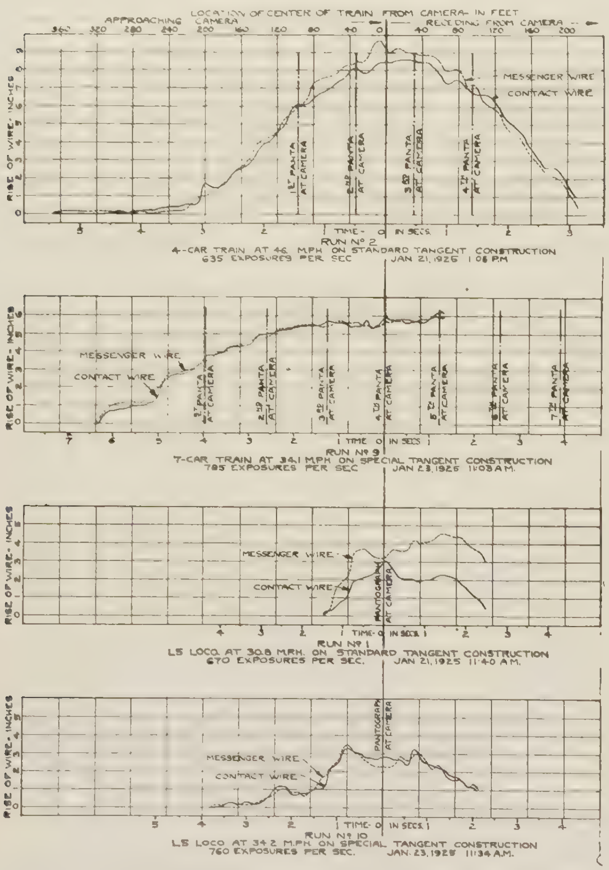

FIG. 9—UPWARD DEFLECTION OF CONTACT WIRE

Measured at center point of catenary span

passage. Even among engineers who have watched such things, the impression is that the deviation of the contact wire from a uniform plane is a matter of a few inches and that the wave of this deviation follows closely the position of the pantographs.

If we assume the messenger as carrying practically all of the weight of construction in a given span and that this weight is fairly uniformly distributed, we obtain an approximation of a catenary curve. The direction of the tension in the messenger makes an angle of varying magnitude with the upward thrust of the pantograph. At the point of maximum sag in the messenger, the tension in the messenger and the thrust of the pantograph are at right angles to one another; as the support points are approached, this angle decreases and is a minimum at the support point. The application of a vertical force applied at the center of sag, therefore, has a maximum effect producing upward displacement of the trolley wire, on account of the fact that there is no vertical component of tension at that point, but only horizontal tension, which is constant throughout the span; whereas at other points than the center of sag, a vertical component of tension exists, which, opposing the upward shoe pressure, reduces the upward displacement of the contact wire. There is little or no displacement of the construction as a whole at the support points such as occurs at the center of sag of the messenger. Displacement at the support point is almost exclusively displacement of the contact wire in relation to the messenger, in other words, a closing up of the space normally existing between the messenger and contact wires.

From what has so far been said, it is to be inferred that there is a major oscillation imposed upon the main

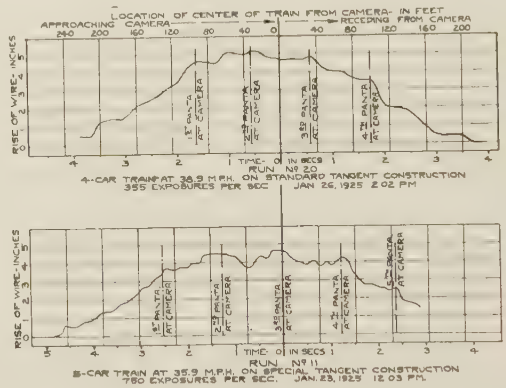

FIG. 10—UPWARD DEFLECTION OF CONTACT WIRE

Measured at trailing quarter point of catenary span

framework of the pantograph, whose periodicity is a function of span length employed and an inverse function of the speed of the rolling stock.

The oscillation of the contact wire travels ahead of the pantograph with various irregularities or harmonics imposed on it. Support points tend to become nodes of the wave. Changes of mass, usually splices, trolley wire intersections or section breaks retard the propagation of these oscillations.

A traveling wave impinging upon a section of greater mass than that employed in the adjacent section is damped to a material degree. As the wave reaches the increased mass, the change of elevation of the contact plane does not take place as rapidly as it did in previous sections of the contact wire and there is produced, locally, a gradient at the approach to such mass of greater slope. This greater slope produces increased pressure between the shoe and the trolley wire which accelerates the shoe downward and the contact wire upward. The pressure produced between the shoe and the contact wire is such as to accelerate the two members in opposite directions at velocities sufficient that they over-travel and contact is momentarily lost.

Such loss of contact is usually caused by definitely establishing an out-of-phase relation between the oscillation of the shoe and the contact wire. There are two other causes of loss of contact occasionally present, however, one being the result of insufficient range of movement of the shoe supports and the other the inability of the shoe to follow in time the periodicity of oscillation of the contact wire.

Taking the more usual case of conditions existing at the time contact is lost, that is, an out-of-phase relation between the oscillation of the shoe and contact wire, the

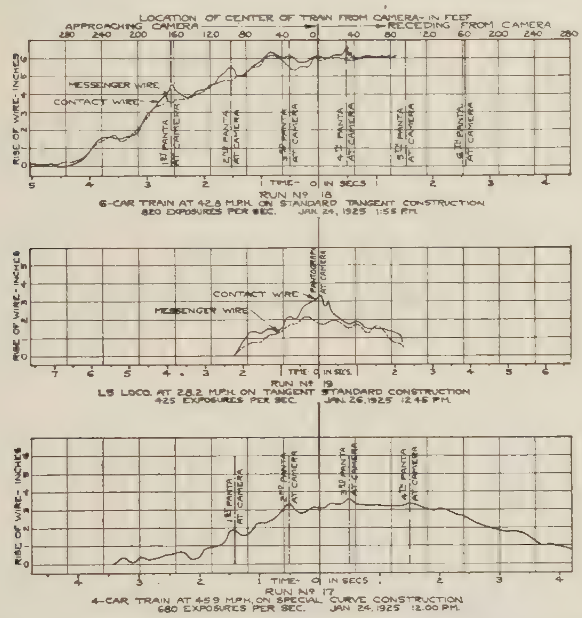

Fig. 11—Upward Deflection of Contact Wire at Splices

Runs 18 and 19—New splice located at center point of catenary span
Run 17—Old splice located 28-ft. beyond catenary support point

succeeding occurrences are, that, as the shoe and contact wire again approach one another, the phase relation of their oscillations is still materially displaced. Contact is made with a pressure increased above normal, due to the vertical velocities present, and excessive wear takes place in these areas.

An increase in the amount of available information on the subject of overhead construction is one of the necessities for eventual railroad electrification.

With this in mind, a study was undertaken some time ago by members of our organization, with the idea of determining and depicting, as far as possible, actual occurrences in the pantographs and in the overhead under operating conditions. This study included a comparison of the design of steady which we have been using for a number of years, with the special design described above.

A section of track was selected in the territory lying between Broad Street Station, Philadelphia, and Paoli, Penn., and a number of spans were equipped with the special support construction referred to. Deflections of the overhead system and movement of the shoes were recorded.

The test apparatus consisted of a high speed camera handling film at speeds from 400 to 1100 exposures per sec., a storage battery for current supply to a shunt motor driving the camera and for use in the projectors, projectors for augmenting natural illumination and a scale used as a background for the contact wire.

One of the center tracks of four was occupied by a tower car carrying the camera, projectors and operators, a storage battery and work car and a steam locomotive. The adjoining track towards the outside of the right-of-way was used as the test track. Outside the clearance lines of this latter track a scale was installed which was used as a determinative background against which the contact wire was to be silhouetted.

The camera and scale were supported at such a height that the camera lens, midpoint of the scale and the contact wire under investigation were at the same

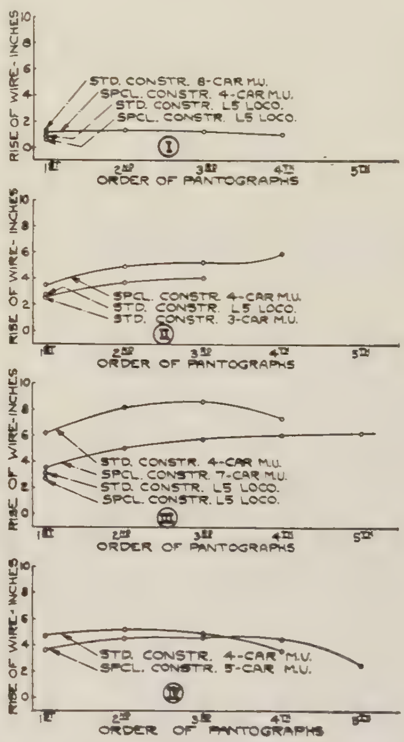

Fig. 12—Relative Upward Deflection of Contact Wire at Each Pantograph

I —Support point
II —Entering quarter point
III—Center point of span
IV—Trailing quarter point

elevation. In front of the scale and held to it by a string was a weight of about five lb., which weight was attached so that its center of gravity was at the zero of the scale. A tripping cord was arranged so that a pull on it would apply a horizontal force on the weight supporting string and break it, allowing the weight to fall.

The camera and scale were located at designated points in the several test spans and, as the multiple-unit train or locomotive approached, its position and

approximate speed was signalled from a point ahead of the test equipment.

The camera mechanism was engaged with the running motor and the timing weight dropped. Some experimentation was necessary to obtain proper sequence and coordination with the passing equipment, but the arrangement finally worked out very well.

A number of determinations were made as follows: Deflections at the center, entering and trailing quarter points of a span and points directly beneath the support points of the messenger. The above trials were obtained for multiple-unit equipment and a portion of them for locomotive equipment, both types of steady construction being photographed.

The exposures made of each test run were then consecutively numbered in 100 exposure intervals and passed through a projector a number of times until the

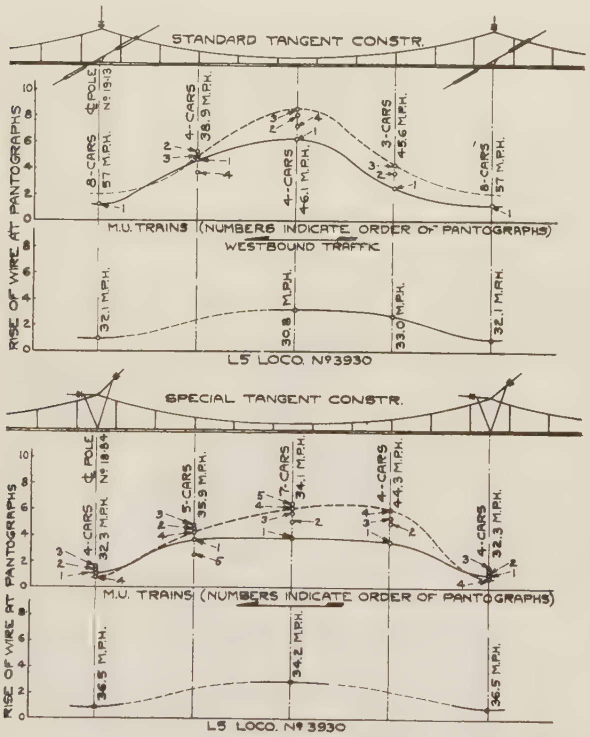

Fig. 13—Relative Upward Deflection of Contact Wire Along Catenary Span

observer was familiar with the film. Then the position of the contact wire in terms of the scale reading was observed at given intervals of the total exposure, with a notation of the exact picture from which the reading was taken. In cases where there existed some peculiar feature or where it was apparent that harmonics of readable magnitude existed, readings at much closer intervals were made.

These data, converted into distance ahead of the train, were then plotted, the ordinates representing rise of contact wire at the observation point in the span from its initial position, and the abscissas representing the position of the train with reference to the observation point at the instant of the occurrence of the position of contact wire indicated by the ordinate reading.

These results, shown graphically, are given in the several figures bearing proper title as to type of messenger support, position in the span of the observation point, type of rolling stock, number of multiple-unit cars, traffic speed and exposure rate.

An analysis of these curves indicates clearly certain conclusions, a portion of which, for a specific design of overhead system, are quantitative. Mathematical conclusions, not included, indicate the basic phenomena to a sufficient extent that usable approximations may be made for construction embodying different weights, span lengths and types of construction.

Such conclusions follow:

1. That a major oscillation is present in the contact member ahead of the pantographs and travels with the pantographs,

2. That this oscillation is of variable amplitude, depending on its location in the span,

3. That the position of any given point in the amplitude of oscillation has a variable spacing ahead of the pantograph,

4. The amplitude varies with the total pressure imposed by the pantographs in a given span,

5. The amplitude seems to be increased with the distribution through a number of pantographs of a given total pressure,

6. That when distribution of a given total pantograph pressure is made through several pantographs, the pantographs in the central portion of a train experience the greatest amplitude of movement,

7. That the leading pantograph does not have imposed on it as great an amplitude of movement as do all successive pantographs,

8. That the direction of traffic does not materially alter the symmetry of maximum upward deflection of the contact wire,

9. That the gradient to which a pantograph is subjected in passing under locations of depressed contact wire height is augmented by a material gradient imposed by the inherent deflections in the approaching spans and that such augmenting of gradient is of the order of the usually installed maximum gradient, one-half of one per cent, for such transition of elevation of the contact wire,

10. That harmonics of the major oscillation are present each side of the pantographs with relatively minor amplitudes and are apparently damped out at pantographs and do not cause trouble,

11. That the presence of material change in mass of the construction adjacent to the contact plane damps the oscillation and thereby causes relatively severe deterioration due to variation in pressure of contact shoes at such points,

12. That with a given increase of mass necessarily locally employed, shaping of the contact surface will decrease the deterioration at such points,

13. That support points practically represent nodes of the major oscillations, as the amplitude of oscillation is relatively small at such points,

14. That the amplitude of oscillation at the center of the messenger span is maximum with a reduction towards each messenger support point,

15. That the amplitude of movement at the center of the span is almost wholly a movement of the total catenary construction, that is, a movement of the messenger and its suspended construction,

16. That the amplitude of movement at support points is almost wholly a matter of change in spacing of the contact wire and its adjacent construction with relation to the messenger wire,

17. That improvement of hanger construction at points adjacent to the messenger support is possible and desirable,

18. That the use of so called flexible hangers at the center of span is not necessary and their desirability is doubtful,

19. That flexible hangers adjacent to the support point may be advantageously used if of satisfactory design,

20. That harmonics in the contact wire at positions of change of mass in the construction adjacent to the contact plane and located remote from support points are of high periodicity and considerable amplitude,

21. That such oscillations cause similar oscillations of opposite phase in the contact shoes,

22. That departure of the shoes from the contact wire at such locations are usually the greatest in time and the greatest in amplitude,

23. That the reduction of changes of mass at points adjacent to the contact plane offers the greatest measure of improvement immediately available,

24. That further study of the construction from a trailing quarter point in a span through the support point to the entering quarter point of the succeeding span offers the next most promising step in improvement,

25. That improvement in the secondary supporting of shoes and the obtaining of a greater amplitude of movement of the shoe is probably desirable,

26. That further investigation and study of the tilting action of shoes is necessary and desirable, as there are indications that edge riding of shoes is at times present to a material degree.

Ground Relay Protection for Transmission Systems

BY B. M. JONES[1] and G. B. DODDS[1]
Member, A. I. E. E. Non-Member

Synopsis.—*The relay problems of an electric power system are most important, and are very vital to the successful operation of the system. More and more consideration is being given to the relay engineers' point of view with resultant improvement in system operation. Several large, successful companies undertake no project having any bearing on the primary electric system without due regard to the relay engineer's recommendation.*

With the transmission networks becoming more and more interconnected, and with the injection into the problem the interconnections with other power companies, the absolute necessity of isolating a faulty line, (or a faulty piece of equipment), is essential and is becoming more clearly recognized by all large companies.

Since this article was written, other 66-kv., ground relay tests have been made with a resistor grounded neutral and with a solidly grounded neutral, and some very interesting and unexpected points were discovered. It is hoped these points will be brought out during the discussion of this paper.

* * * * *

THE question of ground protection has always been a serious one and also a very troublesome one. In the days when transmission systems were operated with a free or floating neutral and one leg of a line became grounded, this would throw a high potential on the other two legs and thus subject the lines and equipment to an unusual strain and possible damage. It would also endanger the lives and safety of people who might come in contact with the grounded line. To locate such a ground in a network was a very hard thing to do and often resulted in outages to a great many customers in the process of finding the line with the fault on it.

The subject of ground relaying is becoming more important, and is attracting more attention in the operation of light and power systems. It is considered absolutely necessary to isolate a grounded line immediately, for several reasons:

1. To reduce chance of injury to people who may come in contact with or approach a grounded line, thereby encountering dangerously high ground potentials,

2. To reduce the resultant damage to apparatus and lines by removing a ground as quickly as possible from the system.

On systems using overhead construction on wooden cross-arms, the ground currents encountered are relatively small and very sensitive ground relays are required to recognize these small currents.

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1. Duquesne Light Company, Pittsburgh, Pa.

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927.

As a result of the troubles encountered with an ungrounded system, a great many companies now make a practise of grounding their transmission system. The grounding of a system may be done in a number of ways, which are shown in Fig. 1. Where the star point of transformers or generators is brought out, this point can be grounded, either solidly or through a resistance. When there is no neutral point available, a grounding

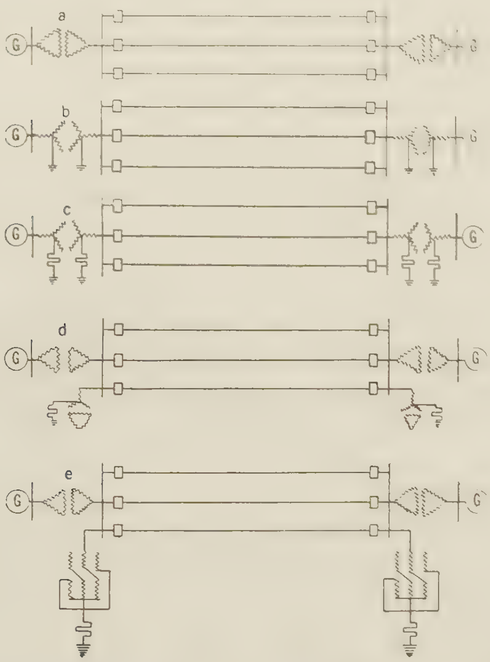


FIG. 1—METHODS OF GROUNDING TRANSMISSION SYSTEMS

a. Early ungrounded systems
b. Solidly grounded systems
c. Resistor grounded systems
d. Star-delta grounding transformer banks systems
e. Zigzag grounding transformer banks systems

transformer may be installed. Grounding transformers are usually connected either star-delta, with the star point grounded, or zigzag, with the star point grounded, both methods having their particular advantages depending upon the particular application.

When the star-delta grounding transformer is used, the star point may be grounded either solidly or through a resistor. If desired, a load may be taken from the delta-connected secondary of the transformer bank. The advantage of the zigzag-connected grounding transformer bank is the relative cheapness of it, since with it no secondary winding is required and thus it is somewhat cheaper than the star-delta bank.

Where the system is solidly grounded, the relaying for ground faults is comparatively simple if the fault current obtained is greater than the load current. In some cases, however, the current for ground faults is comparatively small, due either to long transmission lines or to contact resistance at the point of the fault. Where this condition exists, the phase relays will not protect the line for ground faults, and other means of protecting the lines for grounds must be used. It is interesting to note in this connection that some companies with very long high-voltage transmission lines protect these lines against ground faults only.

On systems which are grounded through a resistor in the transformer bank neutral, the relaying for ground faults is somewhat involved, due to the small ground currents obtained and, in the case of a network, to the distribution of this current through several sets of lines and relays.

Many different schemes for ground protection have been devised, some of which are indicated below:

1. Overcurrent non-directional relay in neutral of current transformer circuit,
2. Overcurrent non-directional relay interlocked with directional elements of phase relays,
3. Power relay with instantaneous time but interlocked with overcurrent non-directional relay for timing,
4. Power relay with self-contained timing element,
5. Impedance ground relay,
6. Power directional relay using inside delta voltage,
7. Balanced current ground relays for parallel lines.

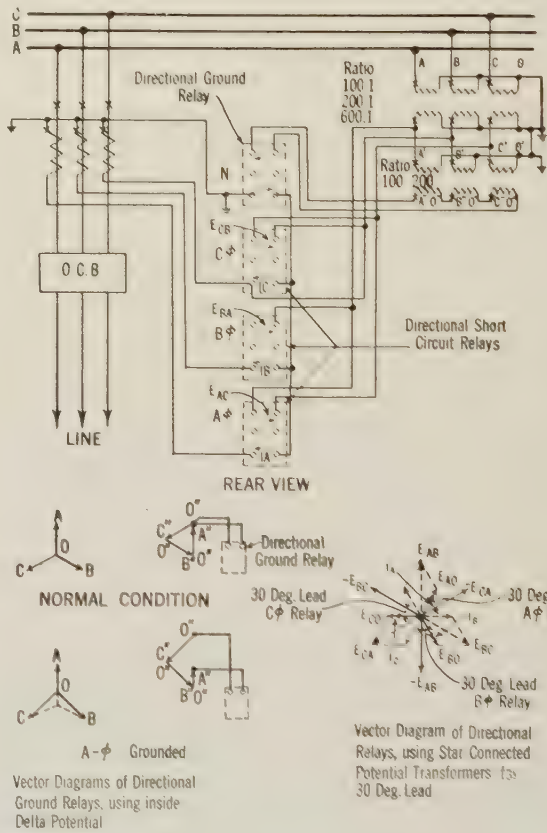


FIG. 2—DIRECTIONAL SHORT-CIRCUIT AND DIRECTIONAL GROUND PROTECTION

The overcurrent non-directional ground relay is satisfactory for use on radial feeders or other locations where directional protection is not required, such as bus or transformer differential protection, or on radial lines. In connection with such uses, a relay with a low operating range and one which puts a small volt-ampere burden on the current transformers is very desirable

and has been developed. This type of relay is very sensitive to small ground fault currents and, due to its low volt-ampere burden, does not overburden current transformers which have other apparatus than relays connected to them.

The overcurrent non-directional relay with its trip circuit interlocked with the directional element of the phase relays was used quite extensively and proved fairly satisfactory in some cases. This type of protection, however, has one main inherent defect which is impossible to overcome. This defect is that on a single-line loop having more than one looped station and having a feed from both ends of the loop, a fault may occur which, while providing enough current to operate the ground relay, will not be of sufficient magnitude to overbalance the load current, with the result that the directional contacts on the wrong set of relays will be held closed and the wrong breaker tripped out.

The power relay has not proven satisfactory for ground protection, due primarily to the fact that a sufficiently low range relay has not been used. With this scheme, the power relay obtained current from the neutral of the current transformers and voltage from the inside delta voltage of an auxiliary set of star-delta connected potential transformers. With this scheme of ground protection and with a fault occurring some distance out on a line away from the substation at which the relays are located, the resultant voltage distortion at the substation may be relatively small, even though the fault currents be comparatively large. Under these conditions of fairly large ground currents and small voltage impressed on the power relay, in conjunction with the poor power factor which sometimes exists during ground faults, the resultant watts in the power relay may be so low that the relay will not operate at all or will operate very slowly. Due to this condition, the possibility of clearing ground faults in a minimum time is decreased.

The low energy power directional ground relay using inside delta potential is one of the most satisfactory schemes. A diagram of connections is shown in Fig. 2. In this scheme the same potential is used as was used in the power relay, but it is used only to operate the directional contacts of the relay, the relay having a separate overcurrent element similar to that of the overcurrent relay. The overcurrent and directional contacts are connected in series as in other power directional relays. In this type of relay, the timing is obtained from the overcurrent element. By using this scheme, the directional elements may be made to operate on a very small number of watts, thereby making it sensitive to very small ground currents. An installation of this type of protection is shown in Figs. 3 and 4, which views were taken in a small substation on a consumer's property, there being one 22-kv. line looped through this station. Fig. 3 shows the front view of the relay panel and Fig. 4 shows the rear view of the panel with the auxiliary star-delta connected potential transformers, and also shows the individual relay test switches for each relay.

The impedance type of relay has been used with reasonable satisfaction on systems which are solidly grounded. These relays may be self-contained, in which case one per phase, or three for a three-phase line, will be required, or the double-element phase and ground relay combined in one case may be used. These relays may obtain their potential direct from the line potential transformers or may use low-tension potential through compensators. The ground impedance relays have the same time characteristics as the phase impedance relays, thereby clearing faults close to the station in a short time and increasing the time for faults farther away from the station. These relays are not so satisfactory, however, for use on a system which is grounded through a resistor, since the voltage drop is usually not large enough to cause the impedance type ground relays to operate in a reasonably short time.

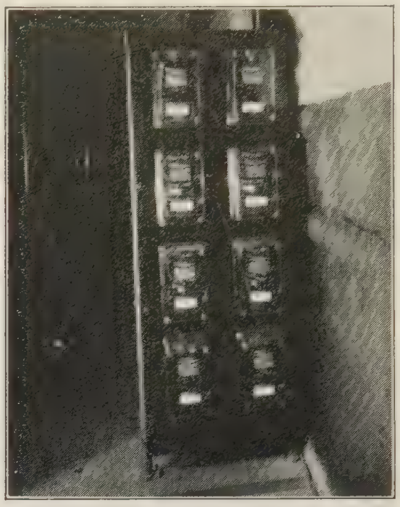


Fig. 3—Front View of Consumer's Relay Installation

Fig. 4—Rear View of Consumer's Relay Installation

The balanced current type of protection is limited in

its application to parallel lines. It furnishes a simple and fast method of clearing all ground faults and is an inexpensive method, for no potential transformers are required. The station must have two sources of feed, however, and when one of the pair of lines is out of service, an extra set of relays is sometimes required in order to permit increased time of operation to obtain selective action with other stations. This type of protection has been described in detail by Mr. H. P. Sleeper.[2]

There are several methods of checking the current and potential phase relations on the ground relays in order to determine whether the relay will operate correctly under fault conditions. Among these methods may be mentioned the following:

1. By using phantom load,
2. By using actual load,
3. By actually placing a ground upon the line.

The Duquesne Light Company, along with several other companies, is strongly in favor of the latter method of checking the direction of the ground relays, having found by sad experience, when using the first two methods mentioned, that mistakes and errors are very liable to occur, with the result that under actual fault conditions, improper relay and breaker operations result.

In connection with the checking of ground relays by actually placing a ground on the line, some very interesting results have been obtained, among which is the relation of ground current to phase voltage with different amounts of resistance in the high tension transformer bank neutral.

This point was brought out very forcibly during some tests conducted by the Public Service Electric and Gas Company of New Jersey which were made in July 1926. A tabulation of their test data is shown in Table I. An analysis of this data shows that with no resistance in the transformer bank neutral, a phase angle of around 90-deg. lag is obtained, and with a resistance of 75 ohms in the transformer bank neutral, the phase angle varies from 5-deg. lag to 15-deg. lag, while with a resistance of 300 ohms in the transformer bank neutral, the power factor ranges from unity to 18-deg. lead. As a result of the poor power factor obtained under conditions of the transformer bank neutral being solidly grounded, the resultant torque on the relay disk is very small, even though the fault current be relatively large, and if the phase angle is greater than 90-deg. lag, the direction of operation of the relay will be reversed.

Similar tests were conducted by the Duquesne Light Company during May of 1926, in order to determine the following points:

1. To determine the minimum amount of ground

TABLE I

DIRECTIONAL GROUND RELAY TESTS

Test Data of High-Tension Line Ground Tests Made by the Public Service Electric and Gas Company

Test number	1	2	3	4	5	6	7	8	9
Date	7/11/26	7/11/26	7/11/26	7/11/26	7/11/26	7/11/26	7/11/26	7/11/26	7/11/26
Time	9:55 a.m.	10:30 a.m.	10:37 p.m.	12:15 a.m.	12:55 a.m.	2:45 p.m.	3:45 p.m.	4.00 p.m.	4:30 p.m.
Voltage of line tested	26 kv.	26 kv.	26 kv.	26 kv.	26 kv.	26 kv.	26 kv.	26 kv.	26 kv.
Bank kv-a	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Neutral resistance	0	300	300	300	300	75	75	75	0
Line grounded	Phase 1 of X-102	Phase 1 of X-102	Phase 1 of X-102	Phase 3 of S-357	Phase 3 of S-357	Phase 3 of S-357	Phase 1 of R-356	Phase 2 of N-196	Phase 2 of N-196
Location of ground	1 mi. from Essex	1 mi. from Essex	1 mi. from Essex	¼ mi. from Metuchen	¼ mi. from Metuchen	¼ mi. from Metuchen	1 mi. from Essex	1/8 mi. from Metuchen	1/8 mi. from Metuchen
No. of ground relays in series on C. T.	1	1	1	1	1	1	1	2	2
Ground relay current setting	0.4	0.53	0.2	0.53	0.53	0.53	0.53	0.5	0.5
High-tension ground amperes	240	64	49.6	90 +	102	178	99	160	420
Ground relay									
Volts	10	150 + (F. S.)	190	180	164	164	146	152	120
Watts	Meter reversed	120	98	240	245	450	230	280	2
Amperes	3.0	0.8	0.6	1.5 +	1.7	2.97	1.65	2.0	9.4
Phase angle	93-deg. lag.	7-deg. lead	10-deg. lead	0	18-deg. lead	10-deg. lag	5-deg. lag	15-deg. lag	90-deg. lag
L-t. star volts before test									
1-N	65.0	66.2	67	63	63	63	63	63	62
2-N	65.1	65.5	66	62.9	62.6	62.6	62.7	63	62
3-N	64.5	65.0	65.5	63	63	63	63	63.5	62
L-t. star volts during test									
1-N	64.5	23	23	106	101	99	24	93	64
2-N	68.8	88	87	98	98.5	97	84	20	33
3-N	63.0	106	106	20	18	18	97	92	82
L-t. delta volts before test									
1-N								110	106.5
2-N								110.5	107.8
3-N								109.2	109
L-t. delta volts during test									
1-N								109.5	103
2-N								111.5	97
3-N								109.2	94

2. H. P. Sleeper, A. I. E. E. TRANSACTIONS, Vol. 42, 1923, p. 513. Discussion, A. I. E. E. JOURNAL, February, 1925, p. 182.

current on which the 50-watt power relays would operate,

2. To make an actual check on the direction of operation of the power ground relays,

3. To determine the effects of putting more than one potential element of the ground relays in parallel on the same set of auxiliary potential transformers,

4. To determine the sensitivity of the low-energy power directional ground relays as compared with the 50-watt power relay.

The test data are shown in Table II and the conclusions arrived at are as follows:

1. The power relays set on a 50-watt tap would not operate satisfactorily with less than a 300-ampere ground, the ground being located at the substation at which the relays were installed. As the ground location would become farther away from the substation, the ground current necessary to operate the relay would become higher, due to less voltage being impressed on the power relay.

2. The direction of all ground relays tested was found to be correct.

3. The addition of an increased number of potential elements of ground relays to one set of auxiliary potential transformers did not result in any noticeable drop in voltage on the secondary of the auxiliary potential transformers. This indicated that the auxiliary potential transformers could be loaded up to their volt-ampere capacity.

4. It was found that the low-energy power directional ground relays would operate satisfactorily on a much lower ground current than the power relays.

Since the above tests were made, low energy power directional ground relays have been installed on the majority of the lines of the Duquesne Light Company 22-kv. system, and a large number of these relays has been tested by actually putting grounds on the lines which these relays protect.

The equipment used in making the line ground tests is shown in Fig. 5. Fig. 5A shows a two-ton trailer on which the necessary equipment for making high-tension line ground tests is mounted. Fig. 5B shows the water rheostat set up and connected to the line. Fig. 5C shows the water barrel emitting flame during line ground tests made at night. Night testing is sometimes necessary due to being unable to obtain the necessary outages during the day. The grounding is done by connecting a water rheostat between the line and a ground connection. The rheostat consists of a barrel inside of which is one fixed and one moveable brass plate. The ground current obtained can be varied by changing the distance between two brass plates immersed in the water. The ground lead is connected to the fixed brass plate and brought out through the side of the barrel. A current transformer is connected in this ground lead and is used for measuring the ground current.

This equipment is all mounted on the two-ton

TABLE II
DIRECTIONAL GROUND RELAY TESTS
Test Data of High-Tension Line Ground Tests Made by Duquesne Light Company

Test no.	1-A	1-B	1-C	2-A	2-B	2-C	3-A	3-B	3-C	4-A	5-B	6-A
Date	5-23-26	5-23-26	5-23-26	5-23-26	5-23-26	5-23-26	5-23-26	5-23-26	5-23-26	5-23-26	5-23-26	5-23-26
Time	9:48 a.m.	9:59 a.m.	10:11 a.m.	10:55 a.m.	10:44 a.m.	11:11 a.m.	12:11 a.m.	12:25 p.m.	12:36 p.m.	12:45 p.m.	2:39 p.m.	4:12 p.m.
Voltage of line tested	22 kv.	22 kv.	22 kv.	22 kv.	22 kv.	22 kv.	22 kv.	22 kv.	22 kv.	22 kv.	22 kv.	22 kv.
Type of C. T.	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing	400/5 Bushing
Line grounded	Beaver F. Morado	Beaver F. Morado	Beaver F. Morado	Beaver F. Morado	Beaver F. Morado	Beaver F. Morado	Morado Koppel	Morado Koppel	Morado Koppel	Morado	Morado	Morado
Location of ground	Morado	Morado	Morado	Morado	Morado	Morado	Morado	Morado	Morado	Morado Koppel	Jct. Pk. MoradoNo.1	Jct. Pk. MoradoNo.2
Bank kv-a.	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Current to ground	60	80-100	Off scale 400	70-80	160	500	400	480	440	440	408	200
Current in ground relay	Could not read	0.5	Off scale	0			4.0				3.5	2.0
Direction of operation of ground relays	Over current non-directional relays installed			Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Volts across pot. coil of relay		5-10	Off scale	10	15	52	47	54	46	44	58	35
L-t. star volts 1-N	62.5	61.5	62.4	62.5	62.5	62.5	49.5	Off	65.	65.	63.5	63.5
Before 2-N	63.0	61.5	61.5	61.5	61.5	61.5	49.5	Off	65.	65.	64.0	64.
Test 3-N	64.5	64.5	62.7	67.7	64.0	67.0	49.5	Off	66.	66.	65.0	64.
L-t. star volt 1-N	61.0	60.0		59.0	53.5	37.0	45.0		68.	42.	67.	67.
During 2-N	64.5	62.5		63.0	67.0	72.0	49.0	45.	52.	70	51	68
Test 3-N	64.0	64.0		63.0	64.0	67.0	45.0	35	75	66	72	68
Neutral resistor	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
Phase angle					18-deg. lag	18-deg. lag						

trailer which is hauled from place to place by a truck. The equipment consists of the following:

1 37-kv. single-pole oil circuit breaker,

1 30-cell, 60-volt battery,

1 Portable control panel with flexible leads 50 ft. in length,

2 Water barrels to be used as rheostats,

1 Water barrel for water supply,

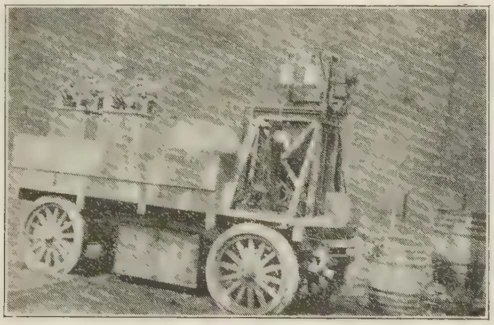
2 Insulated stands on which to place the water barrel rheostats.

2 220-volt regulators,

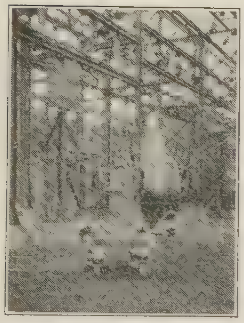
3 Tool boxes for equipment,

3 Current transformers having the following ratios, 500 to 5, 400 to 5, 200 to 5,

3 12-volt flood lights,



A



B

C

Fig. 5—Equipment Used for Making High-Tension Line Ground Tests

a. Trailer and equipment
b. Water rheostat set up for test
c. High-tension line ground tests made at night

Assorted leads of "00" flexible Tyrex single-conductor cable,

Assorted clamps of different types,

A number of pillar type insulators,

First aid box,

Fire fighting equipment,

Blocks and tackle.

The above equipment is all carried on the trailer and provides all of the equipment necessary for conducting grounding tests with the exception of portable meters which are not transported on the trailer but are obtained as required. An ammeter is mounted, however, on the portable control panel and is connected in the current transformer circuit of the grounding lead.

In connection with the testing of relay installations by actually placing faults on the lines, it may be remembered that a paper was presented at the A. I. E. E. Spring Convention held at Pittsburgh during April, 1923.[3] In this paper was described in detail the testing of the relay installations by putting faults on the 66-kv. line.

As a result of the experiences of this and other companies, it is believed that the inside delta power directional ground relaying is the most reliable and satisfactory type of ground protection that can be used on a system having a resistance in its neutral circuit. On systems which are solidly grounded, other types of ground protection are used, among which are the impedance ground relay and the same type of power directional relay which is used for phase protection, except in the case of extremely long lines where, if the fault current is less than load current, other means of protecting the lines must be found.

It has also been the experience of this and other companies that the most satisfactory method of checking the connections of ground relays has been by actually placing grounds upon the lines in question, since there is less chance of error in this method than in any other. It is further felt that the increased cost of this method of testing is entirely justified from the standpoint of the better relay operation obtained, and from the standpoint of reduction in number of interruptions, which is very important.

CENTER OF INDUSTRY IN UNITED STATES

The United States Geological Survey in its annual statement as to the center of industry shows that the new point is about fifty miles southwest of Chicago. This center of industry, it is stated, has moved in the eighteen year period from 1908 to 1926 approximately seventy-five miles in a southwesterly direction.

This slow movement of the center of industry during a period when the capacity of prime movers in central stations and manufacturing plants increased about 140 per cent, indicates in reality marked stability in industrial development in the United States, since the trifling movement towards the western and southern parts of the country are small.

In January 1908 the center of industry in the United States was in the northern boundary of Indiana about one hundred and ten miles east of Chicago. In January 1918, it was still in the northern boundary of Indiana but had moved about fifty miles nearer to Chicago.

3. H. P. Sleeper, A. I. E. E. Transactions, Vol. 42, 1923, p. 513.

The Electrical Resistivity of Insulating Materials†

BY HARVEY L. CURTIS*

Fellow, A. I. E. E.

Synopsis.—*A brief review is given of the literature on conduction through insulators. Every dielectric has a definite resistivity when the potential gradient is below a certain value, different for each substance. If the potential gradient is continually increased, a point is reached where an increase in voltage does not affect the current. This is called the saturation current. With still greater potential gradients, a point is reached where the current increases rapidly and breakdown soon results. All these phenomena of conduction are explainable as the movement of ions in an electric field.*

The resistivity of a dielectric depends on the number of ions in unit volume, on the charge on each ion, and on their mobility (velocity under unit potential gradient). The saturation current depends on the charge on each ion and on their rate of production. Breakdown is preceded by ionization by collision, which is determined by the ionization potential of the substance and the length of path of an ion.

The number of ions normally present in a dielectric depends not only upon the rate of producing them but also upon their rate of recombination. The rate of recombination is a constant of the material, but the rate of production may depend either upon outside agencies or inside forces. In gases, ions are generally produced by outside agencies, the important ones being rays from radioactive materials, X-rays and ultra X-rays. In liquids and solids, ions may be produced not only by the external agencies of rays and radiation, but also by the inside forces of solution and dissociation.

The ionic theory of conduction has been sufficiently developed to explain all the observed facts in the case of gases. Modifications and extensions are necessary, however, before all the experimental data on solids and liquids can be interpreted.

I. Introduction

An insulating material is defined as a material which either does not conduct an electric current or conducts it to a very limited extent only. There is, however, no definite lower limit of conductivity which sharply separates insulators from conductors. In fact, some substance on being subjected to a change in temperature will gradually and continually change from a state which would certainly be called conducting to one which, with equal certainty, would be called insulating. Since there is no sharp dividing line between insulators and conductors, it seems desirable to summarize, briefly, our knowledge of the process of electric conduction before attempting to apply it to the particular case of insulators. This paper will attempt to correlate our knowledge of the conductivity of insulators with the theories which have been put forward to explain the passage of electricity through conductors, and to point out the facts which require an extension of these theories in order that conduction through insulators may be explained.

Electricity is always associated with matter. Whenever there is a current of electricity, there is always a current of material particles. Electric currents can be divided into three classes depending upon the mass of the material particle associated with each fundamental electric charge. These are

1. Electronic conduction
2. Ionic conduction
3. Colloidal conduction.

In electronic conduction the moving electricity is associated only with the electrons. These are extremely small amounts of matter to which the elementary negative charge of electricity is inseparably bound. The most familiar example of electronic conduction is conduction through metals, although many interesting and important applications are found in vacuum tubes. Since electrons are all of the same mass and since the same current and hence the same number of electrons must pass every part of the circuit, there is no measurable transfer of matter in electronic conduction.

In ionic conduction the moving electricity is associated with a subdivision of a molecule, or in some cases, with such a subdivision to which a few molecules are attached. The most familiar example is conduction through electrolytes, although conduction through gases, through fused salts, and even through a number of solid substances is of this type. In this case there is always a transfer of matter, which can be detected at any surface of discontinuity in the materials which form the electric circuit.

In colloidal conduction, the electric current is carried by small masses of matter which are suspended in some inert medium. The electrical precipitation of smoke and dust by an electric current is an application of colloidal conduction.

While the three kinds of conduction are quite distinct, yet any two or even all three may take place simultaneously. As an example, it sometimes happens that when a solvent ionizes, one ion will consist of a single electron, while the positive ion will consist of all the rest of the molecule. Then when a difference of potential is applied, there is both electronic and ionic conduction. A complicated example of this is the Nernst filament at high temperatures, where both ions and electrons participate in carrying the electric current.

While the fundamental distinction between electronic and ionic conduction is the amount of matter carried by the current, yet there are other properties which are

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more or less characteristic. The most important of these is the temperature coefficient of resistance. In metals, this is generally positive, while in electrolytes it is negative. Hence attempts are often made to determine whether a substance conducts electronically or ionically by measuring the temperature coefficient of resistance. At best, this is a very indirect method, and results so obtained require additional confirmation.

The phenomena connected with conduction through insulators depends on the state of the material; that is, whether it is a gas, a liquid, or a solid. The process is more complicated in liquids than in gases, and still more so in solids. Only in the case of gases has a fairly complete explanation of the experimental phenomena been deduced. Hence, in this paper there will be given a brief review of the facts and theories concerning conduction through gases; following this, a digest of some of the more important facts concerning conduction through liquids and solids including a correlation of these facts with the phenomena in gases.

II. Conduction Through Gases

The experimental facts concerning conduction through gases and the theoretical explanation of these facts have been treated in several different books.[1-2-3]

In all cases the authors correlate the experimental facts with the ionic theory. The following is a very brief resume of this theory as applied to gases:

Consider two plane electrodes which are the opposite sides of a cubical box having a volume of one cu. cm. The other sides of the box are perfect insulators. This box is filled with air at atmospheric pressure. If a very small potential difference is applied to the plates for a short time, the current which flows is proportional to the applied potential difference. Hence, under these conditions, the air will obey Ohm's law. The resistance in the assumed case will be about 3×10^{15} ohms. If the potential difference between the plates is increased, the current will increase more slowly than the voltage. When the potential difference is in the neighborhood of 100 volts, the current has become about 10^{-18} amperes. This is called the saturation current, since it does not increase with a further increase in the potential difference. When, however, the potential difference is of the order of 30,000 volts, there is a very rapid change of current with voltage, leading up to the breakdown of the dielectric.

The facts as outlined above can readily be shown by the curve in Fig. 1. It is not feasible, however, to draw to a definite scale such a curve for air at atmospheric pressure, partly because there is considerable variation in the air and partly because if drawn to scale many of the interesting features would be entirely masked. For instance the section of the curve representing the saturation current would extend 300 times as far as the first part of the curve. When drawn to scale, the resistance at zero voltage can be determined from the tangent to the curve at the origin.

1–2–3. For references see Bibliography.

The explanation of the above phenomena is very satisfactorily given by supposing that there is some agency which is continually causing molecules of air to separate into positive and negative ions. These ions usually consist of an atom of either oxygen or nitrogen having a free positive or negative charge equal to the elemental electric charge. In atmospheric air under ordinary conditions the rate of ionization is about four or five ions per cu. cm. per sec. Since in a gas the molecules and ions are in violent agitation, the ions are likely to collide with each other. Whenever there is a collision between two ions having opposite charges, they may unite to form a molecule. When the number of molecules which are reunited each second is equal to the number ionized, a stationary condition has been reached. In normal air, there are always present about 700 or 800 ions per cu. cm. When a voltage is applied to the electrodes of the cubic box, the positive

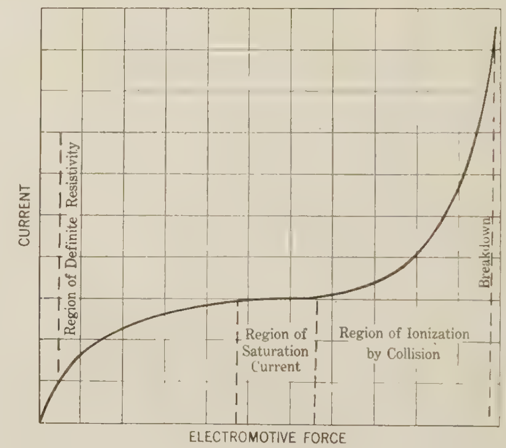

Fig. 1—The Current—Voltage Characteristics of a Gas

ions are attracted towards the negative electrode while the negative ions are attracted towards the positive electrode. On account of numerous collisions with molecules, however, the actual velocity of an ion towards the electrodes is only about one cm. per second if the potential difference of the electrodes of the box is one volt. Hence, if the voltage is very small, the conduction current will not, in a short time, appreciably alter the number or distribution of the electrons in the box. As the voltage is increased, however, the velocity of the ions also is increased. A point is soon reached where an ion is carried from the field almost as soon as formed. Now as the number of ions produced depends solely upon some external agency, an increase in voltage does not increase the current, since the current depends on the number of ions which reaches the electrodes. The saturation current is, then, the current which flows between two electrodes when the potential is sufficiently high so that practically every ion which is formed is carried to the electrodes without combining with another ion. Although the velocity

of the ions increases with increasing voltage, this only decreases the time required for the ions to travel from the place where they are formed to the electrodes, without changing the number which arrives every second.

When the voltage gradient becomes sufficiently high, the velocity of the ions becomes so great that, on colliding with a molecule of gas, the molecule will be broken into ions. Those ions, of which the negative may be a free electron, will then start towards the electrodes and may, in turn, ionize other molecules. Hence, the one ion which was produced by an external agency may be the cause of several ions reaching the electrodes. Therefore, as soon as the voltage applied to the terminals of the cubical box is so high that ions may have a velocity sufficient to produce ionization by collision with a molecule, the current increases rapidly with increasing voltage. This is shown in the latter part of the curve of Fig. 1. It leads rapidly to breakdown, a phenomenon not discussed in this paper.

There are a number of external agencies which will cause a gas to ionize. The best known are X-rays, the α, β, and γ, radiations from radioactive substances, ultra-violet light, and the ever-present radiations of unknown origin which might be called ultra X-rays. The ultra-violet light differs from the other agents in that it generally produces ionization only as it is absorbed by one of the electrodes. In order to simplify the discussion, this type of ionization will not be considered. The activity of the other ionizing agents can be determined from the number of ions produced in a gas, per cu. cm. per sec. As already indicated, the ever-present ultra X-rays produce some four or five ions per cu. cm. per second throughout the habitable volume of the earth's atmosphere. By sinking a small vessel filled with air some 50 or 60 ft. below the surface of a lake, Millikan and his co-workers[6] were able to protect this air from the effect of the ultra X-rays. Some ions were produced in this air, however, which could easily be explained by supposing that the metal of which the containing vessel was constructed bore minute traces of some radioactive substance. While man has never had a mass of gas in which ions were not produced, yet it is possible that under normal condition all ionization of gases is caused by some outside agency.

By using X-rays or rays from radioactive materials, the rate of production of ions can be made as great as a thousand or more per cu. cm. per sec. These recombine rapidly, however, so that no appreciable part of the 10^{19} molecules in a cubic centimeter of air is ever ionized at one time.

In order to develop equations from which the current through a gas can be determined from the applied voltage, the following constants must be known:

Let

q = number of ions produced per cu. cm. per sec. by the ionizing agent.

e = elemental electric charge (1.591×10^{-19} coulombs.)

k_+ = mobility of the positive ions; *i. e.*, the velocity in cm. per sec. when the potential gradient is one volt per cm.

k_- = mobility of the negative ions.

α = recombination coefficient.

δ = ionizing potential; *i. e.*, the potential difference through which an electron must be allowed to accelerate in order to acquire enough energy to ionize a molecule.

If n is the number of positive ions per cu. cm. of gas at a time t, there will also be n negative ions. Now the rate of increase of ions must equal the number of ions produced minus the number of recombinations. But since the chance of a given positive ion colliding with a negative ion is in direct proportion to the number of negative ions, the number of recombinations is proportional to the square of the number of ions. Hence

$$\frac{d\,n}{d\,t} = q - \alpha\, n^2 \tag{1}$$

This equation holds when there is no applied electromotive force. If this condition persists for some time, an equilibrium condition is reached, when $\frac{d\,n}{d\,t} = 0$. Then

$$n = \sqrt{\frac{q}{\alpha}} \tag{2}$$

It is this condition which exists in air under normal conditions.

With a very low potential difference between the electrodes, the number of ions which reaches them depends on the total number of ions in the field and on the velocity of the ions. Hence the conductivity λ is given by the equation

$$\lambda = n\, e\, (k_+ + k_-) = e\, (k_+ + k_-) \sqrt{\frac{q}{\alpha}} \tag{3}$$

The resistivity ρ is the reciprocal of λ. Hence the resistivity of a gas which has been exposed to an ionizing agent for a sufficiently long time for a stable condition to be reached depends on three constants of the gas; namely, the velocity of the positive ion, that of the negative ion, and the recombination coefficient.

The values of these constants for a few of the common gases are given in Table I. While the mobilities are quite different in different gases, yet there is relatively little difference between the positive and negative ions in the same gas. Also the recombination coefficient varies but little for the more permanent gases.

The saturation current S depends only upon the rate of ionization and the volume V of gas between the electrodes. It is represented by the equation

$$S = e\, q\, V \tag{4}$$

TABLE I
IONIZATION CONSTANTS OF GASES

Gas	Mobility of positive ion k_+ $\frac{cm.}{sec.} / \frac{volt}{cm.}$	Mobility of negative ion k_- $\frac{cm.}{sec.} / \frac{volt}{cm.}$	Recombination coefficient α
Hydrogen	6.	7.5	1.4×10^{-6}
Helium	5.	6.	....
Oxygen	1.8	1.8	1.6×10^{-6}
Nitrogen	1.8	1.8	1.6×10^{-6}
Carbon dioxide	0.8	0.9	1.6×10^{-6}
Carbon monoxide	1.1	1.1	0.9×10^{-6}

This does not contain any constant of the gas, but depends entirely upon the activity of the ionizing agent and the volume of the gas from which the ions can be captured by the applied electromotive force.

The ions, in their passage towards an electrode, collide at frequent intervals with a molecule. If, after a collision, the velocity of the ion should be zero, then at the next collision the energy which this ion has acquired is $e\,V\,l$, where V is the potential gradient and l the distance it has traveled. To understand what effect this collision will have on the molecule struck, it is desirable to consider the analogous case of an electron colliding with an atom.

Experiments on gases at low pressures have shown that when an electron collides with an atom, the atom will be ionized only if the kinetic energy of the electron is greater than a certain critical value. The electron will normally obtain its kinetic energy by accelerating in an electrostatic field. Starting from rest, the kinetic energy of the electron at any instant is $e\,V$, where e is the charge upon the electron and V is the potential difference between the starting point and the point under consideration. The value of V, which is just sufficient to give to the electron enough energy to ionize an atom, is called the ionizing potential. Values of the ionizing potential are known for the atoms of most gases.

Likewise a molecule will be ionized by collision with an ion or electron, only if the velocity of the latter is sufficiently high. Since the velocity at impact depends not only upon the potential gradient but also upon the length of path between collisions, the voltage at which ionization by collision will begin increases almost in direct ratio with the pressure.

Our knowledge of conduction through gases at normal pressure, when the applied voltage approaches that which produces breakdown, is very incomplete. There is sufficient evidence to show that the rapid increase of current is the result of ionization by collision. It is not as yet possible, however, to formulate the laws under which it acts.

III. CONDUCTION THROUGH LIQUID DIELECTRICS

The current is carried through most liquid dielectrics by ions. Hence most investigators have attempted to explain conduction through such substances by applying to them the same laws as hold for gases. The discussion of conduction in liquid dielectrics, therefore, centers around the production of ions, their mobility, and recombination.

Ions in a liquid dielectric may result from ionization of the dielectric itself, as is generally the case with a gas, or they may come from the ionization of substances dissolved in the liquid. The same external agencies that cause ionization of a gas will produce ionization in a liquid. In addition to these external agencies, the liquid may ionize spontaneously and ionization is often produced by some physical or chemical action between the liquid and a substance dissolved in it. The first is called ionization by dissociation; the second ionization by solution. As very minute amounts of a dissolved substance may produce a relatively large number of ions, impurities which can be removed only with difficulty often produce more ions in a liquid than is produced by a relatively intense external ionizing agent.

There is some evidence that all liquids are ionized by ever present ultra X-rays. In hexane the number of ions produced per cu. cm. per sec. is nearly fifty times as great as in air[25]. In most liquids the effect is masked by the effects of other ionizing agents.

X-rays and the rays from radioactive substances produce ionization in all liquids that have been examined. The effectiveness of a given ray is different in different liquids. For example, Jaffe[34] found that for hexane the ratio of ionization compared to air is about 1/1000 for α-rays but about 1/10 for β-rays. Also Greinacher[27] found that the number of ions produced by a given beam of α-rays was twice as large in paraffin oil as in petroleum ether.

The rate of recombination of ions in liquids is much less rapid than in gases. The few values of the recombination coefficient that have been determined[26] lie between 10^{-10} and 10^{-13}, or of the order of one millionth of that of gases.

The mobility of ions in a liquid is much less than in a gas. Values for a few liquids are given in Table II.

These values are of the same order of magnitude as the mobilities of ions in electrolytic solutions. There is a large increase in mobility with temperature, as is also the case with electrolytes.

No values of the ionization potential of a liquid molecule are available.

TABLE II
IONIZATION CONSTANTS OF LIQUIDS

Liquid	Average mobility of positive and negative ions—k $\frac{cm.}{sec.} / \frac{volt}{cm.}$	Recombination coefficient	Authority
Petroleum ether	500×10^{-6}	35×10^{-12}	26
Vaseline oil	5×10^{-6}	4×10^{-12}	26
Toluol	0.2×10^{-6}	....	17
Carbon tetrachloride	240×10^{-6}	....	33
Paraffin (60 deg.)	1600×10^{-6}	....	49
Electrolytic solutions in water	3000 to 300 $\times 10^{-6}$	....	17

According to most investigators, the current which flows between two electrodes immersed in a liquid and maintained at a constant potential difference is determined by the differential equation

$$\frac{d\,n}{d\,t} = q - \alpha\,n^2 - s \tag{5}$$

where

n = the total number of ions at time t

q = the rate of production of ions

α = the coefficient of recombination

s = the rate at which ions reach the electrode—proportional to the current

If the ions are uniformly distributed through the liquid

$$s = \beta\,n \tag{6}$$

where β is a constant which among other things involves the mobility of the ions. Substituting this in (5) and separating the variables

$$\frac{d\,n}{q - \beta\,n - \alpha\,n^2} = d\,t \tag{7}$$

Integrating

$$\log_n \frac{2\,\alpha\,n + \beta + \sqrt{4\,\alpha\,q + \beta^2}}{2\,\alpha\,n + \beta - \sqrt{4\,\alpha\,q + \beta^2}} = t\,\sqrt{4\,\alpha\,q + \beta^2 + C} \tag{8}$$

This shows that n is an exponential function of t. It follows that s, the current between the electrodes, decreases as the time during which the electromotive force is applied increases. This same solution holds in the case of gases, but in them, the mobility is so great that equilibrium is reached in less time than that required for the measuring instrument to reach a steady condition. With liquids, however, the mobility is much less and the decrease of the current with time can be readily observed. Most observers have made readings one minute after the application of the electromotive force. During this time, the current will in most cases become stationary.

The conductivity λ of a liquid is given in terms of ionic constants by an equation similar to that for a gas, namely:

$$\lambda = 2\,n\,e\,k \tag{9}$$

where

λ = the conductivity

e = the charge on an ion

n = the number of ions per cubic centimeter in the stationary state

k = the average mobility of the positive and negative ions.

As the mobility of ions in liquids is from a thousand to a million times less than the mobility in gases, the conductivity for a given concentration of ions is proportionally less or the resistivity proportionally greater. The number of ions, however, is generally so much greater in liquids than in gases that the resistivity of many liquids is less than that of gases under similar conditions.

As the potential gradient in a liquid is increased, the current approaches saturation in the same way as in a gas. Difficulties, however, are frequently encountered in the experimental determination of the saturation current of a liquid. As an example, when the number of ions is small, it is probable that most of them will be caused by the solution of traces of impurities. Before the current becomes stationary, many of the ions of the impurities will go to the electrodes, thus removing from the liquid the cause of the ionization. Hence, before the saturation current can be reached, the fundamental character of the liquid has changed.

As a second example, when the liquid contains a large number of ions which have been produced by any cause whatever, an ion concentration occurs near the electrodes before the current becomes stationary. The potential gradient in the region of this concentration is reduced so that the gradient near the electrodes is less than at a point midway between them. On account of this reduced gradient, the velocity of the ions towards the electrodes is reduced and the chance for recombination increased. These two examples show that the experimental difficulties of determining the saturation current in a liquid are much greater than in the case of a gas.

Another difficulty in connection with the determination of the saturation current in a liquid is that ionization by collision may start before the potential gradient is sufficiently high to produce saturation. When this is the case, no true saturation current occurs. This phase of conduction in liquids, however, has received very little systematic investigation.

Much larger potential gradients can be applied to liquids without appreciably affecting the conductivity than can be applied to gases. Thus, in most liquids, the conductivity obeys Ohm's law if the potential gradient is less than three or four hundred volts per cm., whereas in a gas it must be less than one volt per centimeter. Where higher potentials are applied the current does not increase as rapidly as the potential. For example Jaffe[23] found for several liquids that if the potential gradient were between 500 and 3000 volts per cm.

$$I = a + c\,E \tag{10}$$

where a and c are experimental constants.

The resistivity of most liquids decreases with increasing temperature. This is largely caused[16] by a change in mobility, as the number of ions is nearly independent of temperature. Attempts to correlate[11] the resistivity of a liquid with its viscosity, however, have been unsuccessful.

The above explanation of the passage of electricity through liquid dielectrics is based on the assumption that the ionic laws of gases can be applied to liquids. Some investigators are of the opinion that these laws will require some modification before a complete

explanation can be given. Von Schweidler[17] has proposed two modifications; the first suggests that equation (**5**), which gives the rate of increase of ions, should be

$$\frac{d\,n}{d\,t} = f\,(n) - s \tag{11}$$

where $f\,(n)$ is an unknown function. The reason for this suggestion is that the solution of equation (**5**) shows the current to be proportional to the square of the conductivity, while experimentally the current is found to be proportional to the conductivity with a fractional exponent. The second suggestion is that, in many liquids, several different kinds of ions exist, each having a different mobility. When an electromotive force is applied, the kinds of ions having the higher mobilities reach the electrodes more rapidly than those with the low mobilities. As a result, the average mobility of the ions which are left decreases as the time of application of the electromotive force increases. This agrees with the results of tests on several liquids.

IV. Conduction Through Solid Dielectrics

Conduction in solid dielectrics in difficult to distinguish from the phenomena of absorption and residual charge. In this respect, solids are entirely different from liquids and gases in which these phenomena are seldom, if ever, present. Also, electrons play a more important part in conduction through solids than liquids or gases. Ionic conduction, however, is much more common than electronic. Hence in the discussion it will be considered that conduction in solids is caused by ions, the electron being considered the smallest possible ion.

Although the external agencies which cause ionization in solids are the same as in liquids or gases,—namely, electromagnetic radiations and rays from radioactive substances,—the effectiveness of the different agencies is quite different. The α and β rays from radioactive substances ionize some, and perhaps all, solid dielectrics. Also it seems probable that for any given wave length of electromagnetic radiation some solid can be found which will be ionized by it. Moreover there are a number of solids which are ionized by a very wide range of wavelengths. Some illustrations of these facts are cited in the following.

There are few data concerning the ionization of solids by the ever-present ultra X-rays. It may, however, be because of these rays that no substance is known which has infinite resistivity. Sulphur, paraffin, and quartz are ionized by both λ-rays and X-rays. The ionization of selenium by X-rays is so definite that some roentgenologists have proposed using this material to measure dosage. Quartz is ionized by ultra-violet radiation. The visible part of the spectrum produces ionization in a number of substances, the most familiar being sulphur and selenium. In fact, one form of selenium is ionized not only by all of the visible spectrum, but also by the infra red rays.

In addition to the external agencies which produce ionization, substances dissolved in a dielectric may produce it. Familiar examples are water dissolved in rubber and alcohol dissolved in shellac. The influence of minute quantities of a dissolved substance is often very marked. Hence, there is often great difficulty in ascertaining the true resistivity of a substance since it is exceedingly difficult to remove the last traces of an impurity. Some dielectrics ionize spontaneously. There is some interaction between molecules so that ions are always present. With such dielectrics an increase in temperature frequently increases the number of ions in a very marked degree. Glass is an example of such a dielectric.

In general, the mobility of ions in a solid are less even than in a liquid. The values given in Table III however, are not entirely characteristic. In case of light-sensitive selenium, the negative ions are single electrons, the mobility of which is probably quite high, while that of the positive ion is negligibly small in comparison. In this case the conduction is electronic.

TABLE III
IONIC CONSTANTS OF SOLIDS

Substance	Average mobility of ions $\frac{\text{cm.}}{\text{sec.}} \Big/ \frac{\text{volts}}{\text{cm.}}$	Recombination coefficient	Authority
Paraffin	0.14×10^{-6}	....	49

On the other hand the mobility of the positive ions is sometimes high relative to that of the negative. This is the case with some kinds of glass. In such glasses the positive ion can be replaced by other positive ions which are carried into the glass by the current. Many similar cases are known. These examples show that in solids, the difference in mobility of the positive and negative ions may be so great that the conductivity is entirely dependent on the ions having the highest mobility, and not, as is usually the case, in liquids and gases, on the average mobility of the two kinds.

The mobility of the ions in a substance frequently increases rapidly with the temperature. In crystalline quartz[67] the mobility at 100 deg. cent. is about 200 times that at 0 deg., while in calcite it is more than 10,000 times as much at the higher temperature. In rock-salt, on the other hand, there is little if any change in mobility with temperature.

There are few quantitative data on the coefficient of recombination of ions in solids. There is, however, a considerable amount of qualitative information. For instance, it is known that in light-sensitive selenium, practically all the ions are recombined in two or three seconds after removal to the dark. The recombination in crystalline quartz is much slower. At room temperature several months or even years are required before a piece of ionized quartz will reach an equilibrium condition. These examples doubtless represent extremes in regard to recombination.

There are practically no data concerning the ionization potential of the molecules of a solid. There are, however, sufficient data to show that ionization by collision occurs in solids although it is often difficult to separate it from other phenomena which are present when high voltages are applied to a solid dielectric.

It is probable that the law of ionic equilibrium given in equations (**1**) and (**5**) will require modification even in the case of homogeneous solids. At present, however, it furnishes the only accepted basis from which to discuss the observational data. On this basis materials should have a definite resistivity when the applied voltage is low and the time of application long, and should reach, or at least approach, a saturation curve when the voltage is sufficiently increased. Both conditions have been observed.

To conform with this law, conduction current in a solid must decrease with time according to an exponential law, as has been shown to be the case for a liquid. The measurement of the conduction current in solids, however, is complicated by the fact that the absorption current also decreases with the time in much the same way. There is no known method of distinguishing between these currents. In some materials, however, the conduction current is so great that the absorption current can be neglected. Moreover, in all materials, the absorption current tends towards zero, while the conduction current tends towards a fixed value, provided the ionization remains constant. The ionization in solids is generally due to conditions within the material. Often these conditions are disturbed by the passage of the current, so that the current at infinite time does not represent the true conduction current. It follows that no entirely satisfactory procedure can be established. The commercial practise of reading the current at the end of one minute after the potential has been applied appears to be as good a one as any that can be suggested.

The saturation current in solids has occasionally been observed. An interesting case is reported by Jaffe[67], who found that the current in crystalline quartz was independent of the applied potential if the potential gradient was between 10,000 and 50,000 volts per centimeter, and that a steady condition was reached in three seconds after the application of the voltage.

The change of resistivity with temperature depends both on the change in the number of ions and on the change in their mobility. In some solids the temperature coefficient is small and positive, but in most solids it is large and negative. Rasch and Hinrichsen[44] found that, in glass, the change in resistance R could be represented by the formula

$$\log R = \frac{A}{T} + B \qquad (\mathbf{12})$$

where T is the absolute temperature and A and B are constants. This same law has been found to fit a number of substances. As the dissociation of gases into ions (a subject not treated in this paper) obeys the same law, the conclusion is often drawn that the cause of the negative temperature coefficient in such solids is the dissociation of molecules into ions caused by the increase in temperature. This law, however, holds with some solids in which the change in resistance with temperature is known to be caused,—at least in part,—by the increase in mobility of the ions. Hence the dissociation coefficient can be determined from the temperature coefficient only when there is no change of mobility with temperature.

The above deductions concerning homogeneous dielectrics apply to the individual components of a heterogeneous dielectric. The most interesting form of such dielectrics is one composed of layers perpendicular to the direction of current flow. A consideration of this type leads immediately to the question of absorption, a subject which has been treated in another paper* of this series.

V. Conduction over the Surface of Solid Insulators

Gases or vapors are often condensed to a liquid form on the surface of a solid with which they are in contact. If the angle of contact between the solid and liquid is greater than 90 deg., the liquid collects in droplets; but if the angle is less than 90 deg., the liquid spreads, in a film, over the surface of the solid. In one case, the presence of the liquid has little effect on the insulation of electrodes fastened to the solid, but in the other, the current which flows from one electrode to another *through the solid* is often much less than the current which flows through the condensed liquid.

The condensation of water vapor from the air on solid surfaces is a familiar example of surface condensation. With waxes, the condensed water forms into droplets, but with most materials, it spreads in a film over the surface. If the film is formed on the clean surface of an insoluble material, like quartz or amber, the water is very pure. Since pure water is a poor conductor, the film may not carry an appreciable current. The slightest trace of a soluble salt however, will so greatly increase the conductivity of a film that the current through it may be much larger than that through the solid itself. Many solids, such as glass and porcelain, are sufficiently soluble so that films deposited on them are always conducting. The presence of delequiscent salts very greatly increases the amount of condensed water. In all cases, the amount of condensed water increases as a rather large *power* of the relative humidity.

Surface films play an important part in conductivity through porous materials, such as unglazed porcelain, marble, and slate. The pores extend deep into the material. If a specimen is exposed to a humid atmosphere, the pores become lined with a film of water, which

*J. B. Whitehead: *Dielectric Absorption and Theories of Dielectric Behavior*, A. I. E. E. Trans., Vol. 45, 1926, Mar., p. 102.

may have a conductivity many thousands of times greater than that of the material itself. The result is a decrease in the volume resistivity of the material. Evershed considers that conduction phenomena in fibrous materials is associated with surface films in the pores of the material. However, he makes the further assumption that the thickness of the film decreases as the applied voltage is increased. This explains the increase of resistance with increasing voltage which is shown by such materials.

VI. Conclusion

This paper includes only a small part of the facts which are known concerning conduction through insulators. There is every reason to believe that all the known facts can be explained by the ionic theory, the main tenets of which are herein set forth. The details of this theory are sufficiently developed to explain practically all the experimental facts in connection with the passage of electricity through gases. The same cannot be said in regard to liquids and solids. Here the phenomena are more complex and the experimental data more meager. A complete explanation must await further investigation.

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Truck refrigeration on a commercial scale has proved very successful in California in bringing to market from the hot valley interiors butter, eggs, veal and other perishables. On hauls of 215 miles from the San Joaquin valley to the coast not a pound of any commodity has been lost, or its market value reduced by failure of refrigeration or lack of speed in transportation since the service was installed during the early part of the past summer.

Discussion at Kansas City and Bethlehem

PAPERS ON MERCURY ARC RECTIFIERS

(Marti and Winograd[1], Shand[2], Butcher[3])
Kansas City, Mo., March 18, 1927
Bethlehem, Pa., April 21, 1927

(Discussion at Kansas City)

B. Blasser: A limited study on the application of mercury arc rectifiers to a city street railway system brought out some interesting comparisons that might be of interest.

On the property of the Kansas City Public Service Company the daily load factor is almost constant for any week day, varying between 49 and 51 per cent. With this condition, it is a simple matter to construct typical load curves for any season from the average output over the period under consideration as compared to the output on the maximum day in the year.

For the purpose of this discussion the four curves in the accompanying Fig. 1 were constructed; (1) the maximum day in the year taken from hourly readings, (2) the typical winter day which is 81 per cent of the maximum day, (3) average day for the year, 70 per cent of the maximum day, and (4) a typical summer day, 61 per cent of the maximum day.

For a single-unit substation in an outlying district, the time of operation may be somewhat different from a centralized substation and with the application of a 750-kw. unit to the load of 1000 amperes for the maximum hour as shown by Curve No. 1 it is assumed that the station will be shut down whenever the load

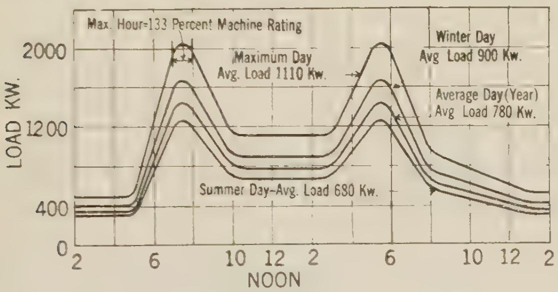


Fig. 1

drops to 200 kw. This operation would give 20.5 hr. operation on the maximum day and 17.75 hr. per day in the summer time. If it should be necessary to operate this station through the "owl" period at less than 200 kw., the comparative results would be materially changed. The dotted line shows the approximate load that would be carried by the machine on the "owl" if this station had its proportionate share of the total load. The 24-hr. operation would give a station load factor of 51 per cent as compared to a load factor under proposed operation of 60.8 per cent on maximum day and 65.5 per cent load factor during proposed summer operation.

In comparing the operation of 750-kw. synchronous converters with 750 kw. rectifiers, the daily load curves shown were used to determine total loss for the day and the difference between the loss with converters and the loss with rectifiers (expressed as a percentage of total output) was plotted against the average load of the machine for the four typical loads shown, Fig. 3A. Positive values show rectifier more efficient and negative values show converter more efficient.

This set of curves shows the effect of load factor and more variation in performance between converters and rectifiers is obtained on 60-cycle systems than on 25-cycle systems.

A similar set of curves, Figs. 2 and 3B, was plotted for a 1500-kw. station using a single-unit converter and two 750-kw. rectifiers in parallel. It was assumed that the rectifiers were operated as a 1500-kw. unit and that one element could not be shut down during periods of light load. The loads were taken as double the values of the load curves shown for the 750-kw. station except that it is assumed that the station is located at an intermediate point between outlying district and downtown making it necessary to operate the station during the "owl" period. It is also assumed that this station will pick up load from surrounding districts so that it will carry a minimum load of 50 kw.

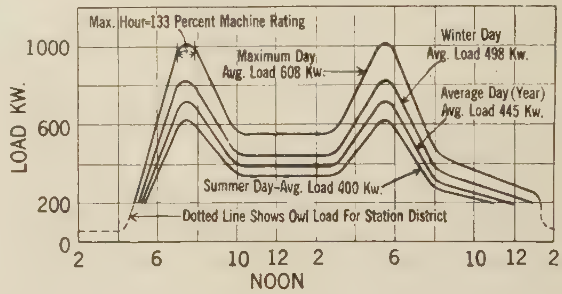


Fig. 2

Even with the additional period of light-load operation, the 25-cycle converter is almost as efficient as the rectifier for the year's operation and is more efficient during the winter period.

On 60-cycle systems, the rectifier is more efficient than converters although the margin is less with the double-unit station.

For the 1500-kw. station, another set of curves, Fig. 3C, was made up with the assumption that one of the 750-kw. rectifiers could be shut down for all loads under 750 kw. This eliminates

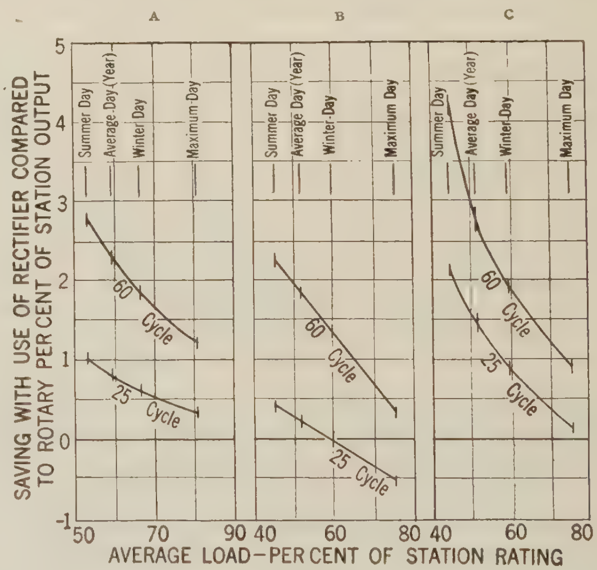


Fig. 3

the loss of one unit over a considerable period of time and results in an increase in efficiency for the rectifier. This operation gives about the same percentage of saving as was obtained with the 750-kw. single-unit station.

From the standpoint of station losses, I should conclude that the application of rectifiers on 25-cycle systems would be justified only after their satisfactory operation in service had been proved, but that the margin of saving when applied on 60-cycle systems is sufficient to justify the expense of trial installations. The tendency of 60-cycle converters to flash over is a further incentive to the trial application of rectifiers on that frequency.

1. A. I. E. E. Journal, August 1927, p. 818.
2. A. I. E. E. Journal, June, 1927, p. 597.
3. A. I. E. E. Journal, May, 1927, p. 446.

CALCULATED DATA USED FOR CURVES USED IN DISCUSSION OF APPLICATION OF MERCURY ARC RECTIFIER

750-Kw. Station—Outlying District

	Load, kw., max. hr.	Hours oper.	Avg. load, kw.	Load factor per cent	Machine factor	Saving with rectifier, per cent	
						60 cycle	25 cycle
Maximum day	1000	20.5	608	60.8	81	1.23	0.35
Average winter day	810	20.0	498	61.5	66.5	1.85	0.64
Average day for year	700	18.88	445	63.5	59.4	2.30	0.83
Average summer day	610	17.75	400	65.5	53.3	2.80	1.02

1500-Kw. Station—Intermediate District
Rectifiers in Parallel at all Times

Maximum day	2000	24	1110	55.5	76	0.32	−0.52
Average winter day	1620	24	900	55.5	60	1.30	−0.05
Average day for year	1400	24	780	55.5	52	1.80	0.20
Average summer day	1220	24	680	55.5	45.5	2.30	0.42

1500-Kw. Stations—Intermediate District
Single Unit 750-Kw. Rectifier Up to 750-Kw. Load

Maximum day	2000	24	1110	55.5	76	0.90	0.10
Average winter day	1620	24	900	55.5	60	1.90	0.89
Average day for year	1400	24	780	55.5	52	2.75	1.40
Average summer day	1220	24	680	55.5	45.5	4.20	2.15

Rectifiers have not been in service for sufficient time in this country to obtain maintenance costs that are truly comparative with other types of apparatus and until this information is available comparisons of total operating costs will have an unknown factor that might lead to erroneous conclusions.

R. G. McCurdy: I wish to discuss briefly the effect on inductive coordination between electric street railway circuits and telephone circuits induced by the use of mercury arc rectifiers. In his paper Mr. Shand refers to the importance of this problem and it is mentioned briefly in the paper by Messrs. Marti and Winograd. It may be of interest to consider the relative advantages of rotating machinery and mercury arc rectifiers in this respect, along with the relative advantages from the power standpoint. It would be unfortunate in this respect if such a new-development should result in a general increase in the a-c. components on street railway circuits in the range of frequencies employed in the telephone circuits, thus increasing the inductive influence of the street railway circuits.

In considering this problem, it should be remembered that the distribution system of the street railways is a system having one side connected to ground. For given magnitudes of voltages and currents of voice frequencies, the inductive effects are much more severe than with circuits which are connected to ground only at neutral points. Moreover, it is of course impossible to employ transpositions in the trolley circuits to reduce coupling with neighboring communication circuits.

As brought out in the paper by Messrs. Marti and Winograd, there are present in the voltage wave shape on the d-c. side of the rectifier, ripples whose magnitude and frequency depend upon the frequency of the fundamental a-c. supply and the number of phases. The fundamental frequency of the ripple is equal to the product of the fundamental frequency of the a-c. supply and the number of secondary phases. The fundamental ripple contains both odd and even harmonics. As the number of phases increases, the magnitude of the fundamental ripple decreases, as is shown by Curve I of Fig. 9 of the paper. Thus in a 6-phase rectifier, supplied from a 60-cycle source, the fundamental frequency of the ripple is 360 cycles, and in a 12-phase rectifier, 720 cycles, the magnitudes of the 720-cycle component in the 12-phase rectifier being considerably less than that of the 360-cycle component in the 6-phase rectifier. If there were 24 phases, the fundamental frequency of the ripple would be 1440 cycles and its magnitude would be much less than that of the 720-cycle ripple present in the 12-phase device.

In the table on the seventh page of the paper by Messrs. Marti and Winograd are shown amplitudes of the harmonic components of the voltage from a 6-phase, 60-cycle rectifier including the harmonics up to the eighth. It will be noted that the magnitudes of these harmonics fall off with increasing frequency. The second harmonic, 720 cycles, is about one-fourth of the 360-cycle component while that of the 1440-cycle component is about one-eighth. It will be seen, therefore, that the 6-phase rectifier has all the harmonic components that the 12-phase rectifier contains and in addition contains 360, 1080 and other odd harmonic multiples of 360 cycles.

As brought out in the papers, there is usually considerable series inductance in the feeder circuits and load of street railway systems. The percentage harmonic in the current is usually less, therefore, than it is in the voltage, the percentage of current harmonic with respect to voltage decreasing with increasing order. In a particular instance which I have in mind, the impedance of the load for the harmonic frequencies was equivalent to an inductance of about one millihenry.

In the table on the seventh page of the paper, to which I previously referred, there is shown also the effect on the wave shape of a series reactor. The rectifier itself at voltages of about 600 has a low internal reactance as compared with the reactance of the feeders and the load. The rectifier acts, therefore, practically as a constant-potential generator of these frequencies. As the impedance of the load varies for these frequencies, the harmonic voltage impressed upon it does not change appreciably. If a series reactor is inserted, it is evident that the total harmonic current and the harmonic voltage impressed upon the load will be reduced in the ratio which the total impedance of the load and series reactor bears to the impedance of the load. In the case cited in the paper by Messrs. Marti and Winograd, the series reactor was about three millihenrys, the load impedance being about one millihenry. There is thus a reduction of about four to one in the harmonic voltages impressed upon the load. It is evident that if the load impedance were larger or the series reactor smaller, the reductions obtained would also be smaller.

It is known, of course, that there are also harmonic ripples present in the d-c. sides of rotating apparatus for converting from alternating to direct current. It will be of interest, therefore, to compare mercury arc rectifiers with rotating converting apparatus in this respect. To date in this country there has been a number of installations of mercury arc rectifiers on street railway systems from which experience has been obtained. These experiences have indicated that the inductive influence on telephone lines of street railway systems will be increased by a factor of between five and ten to one by the use of a mercury arc rectifier not equipped with auxiliary devices for correcting the wave shape, as compared to the influence when rotating converting apparatus is employed. The general experience with induction from street railway systems supplied by rotating converting equipment has been that the noise is largely due to

commutator ripples from the car motors. When mercury arc rectifiers are used, the source of the noise has been due chiefly to the harmonics from the rectifier, the effects from the car motors being overshadowed.

The impedance of rotary converters to the harmonic frequencies is of the same order of magnitude as the internal impedance of the rectifier. When a rotary converter and a mercury arc rectifier are operated in parallel in the same substation through a reactor, the harmonic currents circulate locally and do not get out to the feeders. Under such conditions, the noise effects on the telephone lines will be very much reduced. When rectifiers and rotary converters are operated in parallel in different substations without a series reactor, harmonic currents are exchanged between the rectifier and the converter, which are determined by the magnitudes of the harmonic voltages from the rectifier and the impedance of the feeders between the two substations. The harmonic currents taken by car motors are small as compared to these currents. When these tie feeders are involved in telephone exposure, the effects are particularly severe, the noise being practically constant in magnitude and independent of load so long as the rotary converter and the rectifier are connected to the line.

All types of telephone circuits are affected by these induced disturbances, including interoffice trunk circuits used for private-branch exchanges and party-line subscribers' circuits. Individual subscriber circuits are also affected under some conditions. These circuits are affected even when they are carried in underground cables.

Reference is made in the paper to a small percentage of cases involving mercury arc rectifiers which have given telephone troubles, but, as I understand the matter, this figure is based upon European experience. So far, experience in this country has indicated that the percentage which will require remedial measurements will be very much higher than that. Our experience has been that where these mercury arc rectifiers are connected without auxiliary devices for modifying wave shape to street railway circuits involved in telephone exposures, severe noise is caused in the telephone circuits. In two or three instances it has been necessary to temporarily shut down the mercury arc rectifier until a remedy could be applied.

In cooperation with the manufacturers of these rectifiers, and with the street railway companies that are particularly involved, work is being carried on by the American Telephone and Telegraph Company and Associated Telephone Companies to determine remedial measures. Consideration is being given both to measures that may be applied to telephone circuits so that they may withstand a higher degree of inductive influence, and to corrective measures which may be applied to the mercury arc rectifiers to reduce their inductive influence.

In reference to the latter, consideration is being given to the use of filters. One particular arrangement which is being investigated consists of a series reactor having an inductance of about one millihenry, with three shunt branches, each consisting of inductance and capacity tuned for the 360-, 720- and 1080-cycle components. This arrangement gives large reductions in the magnitudes of those particular harmonics and appreciable reductions in the magnitudes of the harmonics of 1440 cycles and above. With such a filter connected to the rectifier, its telephone interference factor will be reduced to that of a reasonably good rotary converter. Under such conditions it would seem to make no particular difference, so far as inductive coordination between the d-c. circuits and telephone circuits is concerned, whether the power were obtained from a mercury arc rectifier or from rotating converting equipment. At present, it is not possible to give any precise figures on what the cost of such a filter will be, but it does not seem that it will very materially change the cost comparisons between mercury arc rectifiers and rotary converters.

In addition to the effects involving the d-c. side of the rectifier, there is also a problem of wave-shape distortion on the a-c. side. The current input to the rectifiers from the a-c. supply contains harmonics of considerable magnitudes. The effects on the telephone interference factor of the voltage depends upon the relative ratings of the rectifier and the generating system and the impedances of the feeders to the harmonics. If the rectifier load is small as compared to the power capacity of the generating system and the feeder is short, the effect on the a-c. system is not large. If rectifiers form a large proportion of the load, such as might be the case with a main line railroad electrification, the effect on the a-c. voltage and current waves would be important and the difficulty of coordinating the a-c. supply circuits with neighboring telephone circuits would be materially increased. There is an important difference, however, in that these harmonics are in the balanced voltages and currents rather than in a circuit having ground as one side.

A. S. Biesecker: In connection with the first method of which you spoke—that is, the introduction of the reactance in order to smooth out the current curve—by what percentage is that going to affect the regulation?

R. G. McCurdy: The regulation of the rectifier is effected only by the d-c. resistance of the series reactor. The power losses in the shunt elements are entirely negligible. There seems to be no particular difficulty in designing the series reactor to have a voltage drop of 0.5 per cent or less of the rectifier voltage where this is 500 volts or above. With lower voltage rectifiers, of course, the loss in the series coil would be more serious.

G. E. King: What, in microfarads, is the capacity of the condenser you would have to put in there?

R. G. McCurdy: In the particular arrangement I have described, which is applicable to a 600-volt, 60-cycle, 6-phase rectifier, the series reactor is one millihenry and the reactor in each of the three shunt branches is two millihenrys; approximately 100 microfarads are required in the 360-cycle branch, 25 microfarads in the 720-cycle branch and 10 microfarads in the 1080-cycle branch. A design involving more inductance and less capacitance would be more economical for higher d-c. voltages.

A. S. Biesecker: Does it require as much capacity as that for each installation?

R. G. McCurdy: That is one of the matters which must be determined by the cooperative studies by the manufacturers and street railway and telephone companies, to which I have referred. It is obvious, of course, that if the mercury arc rectifier were connected to a trolley system which is not involved in telephone exposures, no filter of any sort would be required. As a rule, however, wherever we find street railway systems, we are likely to find telephone systems in proximity so that some filtering equipment will be required. The total amount of capacity required will, of course, be determined by the reduction in harmonic voltages and currents which must be obtained.

O. S. Clark: Is the trouble caused by harmonics in the rectifier comparable with the trouble caused by harmonics in the rotary converter?

R. G. McCurdy: While there are occasionally encountered rotary converters which have fairly large harmonic components in the voltage wave, approaching those of the mercury arc rectifier, as a rule, rotating equipment has noise-producing harmonics amounting to not more than 10 per cent or so of a six-phase rectifier not equipped with correcting means. In a number of instances where rotating apparatus having these large harmonics has been encountered, these harmonics have been reduced by the application of auxiliary devices, such as resonant shunts. As a rule, there has been sufficient series impedance in the generator or converter to make it unnecessary to introduce a series reactor.

R. E. Curtis: The Luzerne County Gas and Electric Corporation has had experience with harmonic filters. We have installed a filter on a 25,000-kv-a. generator for this very trouble, and I wonder if the American Telephone and Telegraph Com-

pany is not in a position to stand the expense for any of these harmonic filters that are required.

R. G. McCurdy: I feel that this matter of the division of cost of coordinated measures between the power and telephone companies is somewhat beyond the scope of this discussion. It seems to me, however, that when any utility is considering the use of new apparatus or methods of operation resulting in operating economics to the particular utility employing it, a study should be made to determine what methods of inductive coordination would be required by the introduction of the new apparatus or methods. It seems obvious that over-all economies should be considered rather than the individual economy to any particular utility, and the introduction of any new devices or methods, which require for inductive coordination the expenditure of sums of money larger than the amount involved in the operating economies, is a step in the wrong direction. The whole matter of inductive coordination should be attacked from the standpoint of the best engineering solution using apparatus and methods in the plants of both utilities which will permit them both to meet their present and future service requirements effectively and at a minimum total cost.

Caesar Antoniono: We have been listening mostly to one side of the story, the manufacturers'. We have one of these rectifiers which was put in operation a year ago last June. At that time we had in Chicago the problem of handling the crowds of the Eucharistic Congress, which was one of the biggest tasks that any railroad ever undertook—to carry such a large number of people over such a distance in that time. This rectifier station was the last leg of the outfit. We had confidence in it. We had to install eight substations to take care of that load. About 18 mi. of double track was built to take care of that. So, this rectifier was very much depended upon.

Just to show you what we know about the rectifier and what we don't know— it seems there are many things we don't know about it yet. The theories presened here this morning I take with a grain of salt—some are true, or they appear to be true, so far as our experience goes.

At noon before the Eucharistic Congress we were still baking out the rectifiers, uncertain whether we were going to have them in service or not. It developed at noon that we had one anode leaking on one tank. Consideration showed that if we were going to take the tank apart again and try to re-seal the leaking anode, we would not be able to re-bake it in time to put it into service. That service was to begin at three o'clock the next morning, and this was noon.

It was decided, therefore, to take a change, therefore, inasmuch as by keeping the vacuum pump running, it would keep the vacuum up. We put it into service that afternoon. It carried a light load—until 3 a. m. From then on, the rectifiers stood up under momentary peaks of 300 per cent load without a flicker or any effect apparently on the rectifier. The only trouble we got into right off— when it began to pick up the load—was heating. It seems that the way we had arranged the cooling water was not proper to take care of this load.

This substation was installed in the country and the cooling water is pumped continously from a well. The first idea was that the well water was perhaps too cold to apply to the cathode and to the tanks and, therefore, it was considered the best policy to discharge the water back into the well case. Right away we warmed that too much. So, it was necessary to discharge the water outside and we went through that day without any hitch at all as far as the rectifier carrying the load was concerned.

It happened that a few weeks after that, the designer of that particular rectifier came on the job and we told him the anode was leaking. He said, "Well, if I had been on the job, it wouldn't have been put on the line." That anode was there until a month ago, when for some reason the factory decided to change it. It was considered that a perfect vacuum must be had to run. This rectifier had a leaky anode running for ten or eleven months without causing any trouble.

Now I am optimistic in believing the mercury rectifier has a field, and if some of the properties will make trial stations, I think that the troubles will be overcome pretty quickly.

We have been compelled by ordinances in some towns not to put up certain types of buildings in certain locations. That will ban the converters from those locations on account of the noise unless an expensive structure is designed to be sound proof.

There is another place where the rectifier adapts itself very readily to the load in certain conditions. This is at a railroad crossing. Our trains may approach a crossing at a speed of 75 mi. per hr. and then slow down to 15 mi. per hr. which is the ruling of the commission, in crossing the railroad. The result is when a train approaches the crossing, at a distance of about 2 mi. it shuts off the power and goes over the crossing without power. When it gets on the other side of the crossing power must be available. With the rotary converter station it is necessary to set the relays very high or slow, otherwise the station may shut down. It takes from 25 to 35 sec. to get the station back on the line. Rectifiers have proved to be better equipment for that class of service. The rectifier picks up the load right away when the trains get on the other side of the crossing, in about 10 sec. We haven't heard of any telephone interference. We have a private telephone cable for the railroad's use passing right by the station and there is no interference there. The telephone property is about ¾ mi. away and there is no interference at this time, although in that same vicinity we have had radio complaints on the rotary converters.

There are other things that appear to be in favor of the rectifier as against the converter. One thing we have to contend with in the rotary converter is flashing over and locking out. That seems to be in some cases quite serious.

Then, we have the commutator and brush troubles. Every one knows the troubles of the commutator of a high-speed machine. Also the a-c. brush is as much trouble to the converter man as the d-c. brush on account of serious dust. The dust spreads all over station equipment and causes troubles on contacts and insulation.

A question has been asked about the load division. This load division question brings us back again to what we don't know about the rectifier. We had a case where one starting anode stuck closed for over a week and would not draw an arc and pick up any load. During this time we assumed the two tanks were working though one was not. Without any apparent trouble one tank was doing the work both were supposed to do. We didn't know the difference.

As to repairs, as has been brought out, we have not had much experience on what repairs amount to, but the impression I got is that the repairs are not going to be anything as compared to those on rotary converters.

A. Herz: Mr. McCurdy mentioned something about telephone interference. On that subject Mr. McCurdy can tell you more than I can, but the audibility or sensitivity curve of the human ear is, I think very interesting. From analysis of the inductive influence liberated by these rectifiers, we know that a great percentage of induction is in the order of the 6th harmonic, that is, 360 cycles. Another large batch of it comes in at the 36th harmonic, that is, 2100 cycles. Between these there is a valley in this induction. This, of course, is a favorable circumstance and is a material help in the problem of inductive coordination.

It is an interesting fact that the inductive influence caused by the rectifiers is really in the valley of the sensitivity curve of the human ear. It may come in higher up again, as some claim that the human ear has two sensitive spots, one of which is much higher than the one I have mentioned.

Changing the subject, this matter of having substations 3¼ mi. apart on heavy electrification raises the question where are we going to stop? If we increase our traffic we shall have to put in substations 1½ mi. apart. assuming the use of 700 volts or

less on the trolley. The rectifier now gives us an opportunity to increase the voltage. I believe it is very opportune that it does. When you have to put substations in at spacing of 1½ mi. it is nearly time to increase our trolley voltage. Certainly 1500 volts is practically out of the question in city electrification on the streets; 1500 volts or higher is more applicable to interurban or main-line electrification and electrification outside of the cities.

I believe the Europeans have gone a little deeper than we have into the transformer construction layout used in connection with the rectifiers. If the transformer is the answer to some of the troubles we have we should have the transformers made in Europe or else our manufacturers might be induced to change to the better way.

The subject of speed of operation is vital. The rectifier can be placed in service in a few seconds. You have to pay no attention to synchronizing. As a matter of fact you can get a rectifier on as quickly as your switches will operate. With rotaries that is out of the question, especially with 1500-volt installations where you have two rotaries in series. The question of polarity on the rotaries is very important, but not so with the rectifier—it comes up correctly every time.

As regards noise both within the substation and outside, we must acknowledge that the advantages are all with the rectifier.

Flashovers have been mentioned. Flashovers on rotaries are bad—we know it. Flashbacks occur in rectifiers, but I feel confident that they are less serious to the system and I am sure they are not as hard on the operators.

In the matter of cooling these rectifiers, we have had certain difficulties caused by electrolysis. Parts of these rectifiers float 1500 volts above ground and when a semi-conductive cooling medium is used there will be some current leakage. I wonder why the manufacturers don't go to oil cooling, using the same oil over and over again and cooling this with water through cooling coils. That would mean a change in apparatus but I am quite sure it is feasible. Attempts to overcome this difficulty by the use of distilled water have been unsuccessful; within two weeks it becomes contaminated to such an extent that it is worse than Lake Michigan water normally is. So, I think serious consideration should be given to cooling methods, making use of oil.

W. C. DuVall: It seems to me in this big subject of rectification, it is going to be a matter of economics and I am quite confident that we are going to do in the future the same as we have in the past—engineers are going to find ways and means of correcting such things as telephone interference and other factors that would be in the way of progress.

The biggest thing that the rectifier is doing is to help fight the battle of electrification of railroads, alternating current versus direct current, and no doubt, we are going to sift it down to a field where the rectifier will take its place at one end, and the converters the other. Just where that division is going to be it is hard to say, but in any event, I am sure engineers will find a solution.

W. B. Anderson: In the latter part of his paper, Mr. Shand mentions a series of tests on one of the old rectifiers, Unit No. 56, which was built by the Westinghouse Company in 1916. These and other later tests were made by the writer, who is associated with Mr. Shand, to obtain a direct comparison of certain features in the old and new designs. The older unit was operated for approximately three months. The results were such as readily to convince anyone that successfully operating steel-tank rectifiers were made by American manufacturers previous to their present commercial activity.

The vacuum chamber of Unit No. 56 is a drawn steel tank 19 in. in diameter and 26 in. deep, this being supported by an outer sheet metal casing which also serves as a water jacket. The two anodes are made of drawn steel and constructed to permit circulation of water for cooling. Steel anode shields are used and the cathode is not insulated from the rectifier tank. The unit is also equipped with a Pirani type of vacuum gage, the same principle now being applied to what is more commonly known as the "hot-wire" vacuum gage. All of the seals are made with "vacuum cement" a sealing compound developed especially for mercury-arc rectifiers. This cement is still one of the best materials that can be found for vacuum tight seals for certain applications.

As Mr. Shand states, this rectifier had been out of service for more than eight years. The tank was opened, cleaned and reassembled, the only changes being the replacement of an old solder valve with a modern diaphram-type valve. A set of vacuum pumps and a McLeod gage was added to make the rectifier an operative unit.

The rectifier was operated at different voltages from 175 to 750 volts and on continuous loads as high as 700 amperes It was operated 24 hr. per day for a week on a motor-generator set load of 600 amperes without a single interruption. Overloads as high as 1200 amperes were thrown on the rectifier for 5 min. with no apparent distress. Higher momentary overloads tending toward short circuits merely opened the circuit breakers. Operation was resumed as soon as the breakers could be closed again. Several times the pressure was allowed to increase until an internal short circuit occurred. Following these, the tank could be pumped out again in three or four minutes and operation resumed. The internal design with the steel shields seemed to withstand rather abusive operating conditions.

Two methods of supplying cooling water to the anodes were tried. In the first method, a part of the tank discharge water was passed through the anodes. This meant that with normal full load operating temperatures, the anode intake water temperature was about 35 deg. cent. When starting, the anodes were at room temperature or lower. The other method, which is similar to the practise of ten years ago, was to recirculate the anode discharge water, adding just enough make-up water to maintain a predetermined temperature. Before placing the rectifier in service, the anode water was heated to permit starting with warm anodes. The latter method proved much more satisfactory. Operation at uniform and higher anode temperatures was possible and the necessity of starting with cold anodes was eliminated.

With such an anode-cooling system, it was possible to collect some interesting data and verify certain ideas relative to the proper temperatures at which anodes should be operated. Several mornings when starting up after the rectifier had been standing all night, full load and overloads were thrown on the rectifier. With cold anodes, the first few minutes of operation were very unstable and internal short circuits frequently occurred. By preheating the anode water, operation was made stable and there were no short circuits.

For continuous operation, the anode water intake and discharge temperatures were limited to values corresponding to the limiting temperature of the seals. On several occasions, these temperatures were allowed to increase approximately 50 per cent for periods of about 2 hrs. following continuous operation at the first mentioned temperatures. The result was improved vacuum and increased stability under abnormal operating conditions as compared to similar operation with normal anode water temperatures. These tests demonstrated very forcibly the desirability of relatively higher anode temperatures.

As already mentioned, the loss in the rectifier was dissipated either in the anode and the tank cooling systems. Measurements indicated that at full load, approximately 65 per cent of the loss was dissipated in the tank cooling water and 35 per cent in the anode cooling water. These values represent continuous operation at the most satisfactory discharge water temperatures for this particular design.

One interesting and very noticeable thing connected with the operation of this old rectifier was a decided improvement in vacuum when it was placed on load after standing idle a few hours. This was apparently due to a redistribution of pressure.

As Mr. Shand has pointed out, one of the objectives of the

older rectifier development was the perfection of a rectifier normally requiring no vacuum pumps. The tests on Unit No. 56 indicated that rectifiers can be made to operate for long periods without pumping. Rectifiers with such a high degree of vacuum tightness are not required now. Vacuum pumping equipment that is simple, compact, and reliable is available. With a rotating oil vacuum pump and a mercury diffusion pump such as used on modern steel rectifiers, it is possible to evacuate a tank of 13-cu. ft. volume from atmospheric to 0.001 m. m. of mercury pressure in 60 min.

E. F. Sipher (communicated after adjournment): Mr. Shand has very accurately given the steps in the development and I believe that the decision to operate a rectifier with a pump running continuously is the turning point in the development. Until the latter part of the development described by Mr. Shand, we attempted to secure exceptional vacuum-tight joints because the pumps which were available then were very expensive and could not maintain a high vacuum against the small leaks. With the advent of the diffusion pump, about the time work was discontinued, the possibilities of operating with the pump running continuously and building rectifiers with a less perfect seal were being seriously considered.

If the operators will accept steel-tank rectifiers, which must be pumped frequently or continuously in order to maintain a vacuum, I can see no reason why it should not be possible to furnish rectifiers of considerable capacity, and which will operate satisfactorily, as it will no longer be necessary to build seamless drawn steel tanks, nor to construct extremely tight vacuum joints, which are inherently expensive and hard to maintain.

(Discussion at Bethlehem on Marti and Winograd Paper Only)

L. A. Doggett: Referring to the table, where the comparison is made on the efficiency basis between the rectifier and the motor generator set, it seems to me there ought to be another column in that table that would include the rotary converter, for it seems to me the rotary converter of a 3000-kw. size would have an efficiency of nearly 96 per cent which would make the efficiencies almost equal for the two rectifying devices.

A. J. Standing: There are three questions that probably have been covered in this paper but unfortunately I have not had an opportunity to read it. The first question is: Are rectifiers available in 25-cycle 6600-volt circuits? The next question is: Are rectifiers affected by changes in temperature? And the third question is: what is the maintenance on them and what troubles are they subject to?

J. T. Waugh: I would like to ask Mr. Marti, what information he has on the reliability and maintenance of mercury-arc rectifiers, as found by experimentation or actual practise? Can he give us the relative cost between a rectifier with its transformer equipment and a motor-generator set of approximately 50 to 100 kw. and for say 220 volts d-c.

John Grotzinger: It is evident that the application of this rectifier to electric-traction substations is offering decided advantages.

Unfortunately this does not apply to industrial plants where d-c. at 240/120 volts is required for the operation of small and medium-sized variable-speed motors. I take it that for a three-wire system two rectifiers would be required, one on each side of the neutral, operating at 120 volts d-c.

At this low voltage there is no gain in efficiency over the motor-generator set and the cost of the rectifier would be excessive. The attractive feature in such an arrangement would be the freedom from the compounding trouble met with when operating several three-wire generators in parallel.

I would like to have Mr. Marti tell whether in operating several such units in parallel they divide the load uniformly, also what takes place in the case of a short circuit.

G. M. Kennedy: I want to know whether you use a three-phase transformer or a single-phase. Suppose we had a 300-kw. rectifier, what transformer capacity would we use with that?

W. H. Lesser: How does the attention required with these rectifiers compare with the attention that we need with an automatic motor-generator set or an automatic converter?

O. S. Clark: Fig. 5 shows increased tendency in Europe toward higher voltages. I wonder if this is being done to reduce distribution losses, or does it indicate a tendency to adopt the mercury-arc rectifier which operates more efficiently at the higher voltages.

D. C. Prince: On this question of telephone interference the General Electric Company has taken the position that we have to go halfway with the telephone company, and I believe all the rectifiers which we have put out are equipped with the reactance which Mr. Marti shows at the top of his figures.

On the question of filters it has been a matter of where the exposure has been bad, and in our installations in most cases the exposures have not been bad enough to require the filters. However, there seems to be still some hidden question regarding that, because one hears all sorts of stories about what interference this rectifier and that rectifier produces. So far, our rectifiers with the series line reactance have made no trouble in the places where they have been fed over heavy power lines, and it is observed that if the rectifier is supplied over a large power line, so that it is a relatively small part of a power load, the interference seems to be considerably less than where the rectifier is the only piece of apparatus fed over the entire line. A definite correction procedure will probably be developed as a matter of experience, and I don't believe the cost will be great. In most cases where we have had to put in the filters the cost has not been prohibitive.

Mention is made that a rectifier is naturally a continuous-rated machine. The rectifier itself is only a small part of the installation, and for that reason the characteristics of the rectifier are not necessarily imposed on the system as a whole; that is, if it were desirable to supply any particular 2-hr. rating, the fact that the rectifier might come to its final temperature inside of half an hour would not make it necessary to supply a complete installation on the basis of half an hour period overload; *i. e.*, the fact that the rectifier itself is a relatively small part of the whole makes it possible to discount its own particular characteristics by supplying a margin in rectifier capacity. We have installed in Chicago a rectifier with a capacity of 1500 kw., and this unit has repeatedly carried loads of over 9000 kw. with no ill effects whatever. We hope that the policy will be to install rectifiers of sufficient size to handle anything that can come, and then, as the device becomes more exactly known, it may be possible to make savings, but there again such savings will only be in the rectifier, which is but a small part of the whole installation.

Mr. Marti has also gone into this question of the rating of transformers. The transformer rating for a three-phase rectifier is somewhere around 130 per cent of the kw. capacity, and for a six-phase rectifier he has given the figures as somewhere around 150 per cent, and that leads to the question: Aren't we sacrificing something by going to polyphase operation; that is, to a higher number of phases? We have made an investigation to see if the advantage in wave form of the higher number of phases cannot be obtained with three-phase units, which have the advantage not only in that the transformer ratings are less, but the regulation also tends to be better and the telephone interference tends to be less. As a result, our standard rectifiers, instead of being six-phase or more, are all three-phase, connected through interphase transformers, either two or four units operating at an angular displacement to bring the total phases up to six or twelve.

Sidney Withington (communicated after adjournment): There is no doubt that mercury arc rectifiers possess many material advantages as compared with rotary apparatus, either converters or motor-generators. They are relatively simple in their operation and, being static, are especially adapted to automatic

substation operation: furthermore, they can, like transformers, be placed on the line instantaneously by the closing of a switch as required to take care of sudden unexpected loads. As Messrs. Marti and Winograd have pointed out, rectifiers are especially advantageous for high voltages, both from the point of view of their operating characteristics, and cost as compared to rotary apparatus. Then, too, as has been stated, they are very attractive as regards efficiency, especially at fractional loads. It should be borne in mind, however, that the relation between overload capacity and continous rating is relatively unfavorable as compared to rotary converters or motor-generator sets, especially for steam-railway electrification. Where the load increments are relatively large compared to the total load, and where, therefore, the peaks may be of but short duration, the overload capacities of rotary apparatus are of value, whereas the relatively small thermal capacities of the rectifiers are a limiting factor. In the case of urban traffic, where the load increments are a relatively small part of the total load, this feature is of less importance, and this is the field in which the greatest development of the rectifier will undoubtedly lie.

An important characteristic of mercury rectifiers is that if they are subjected to conditions which are too severe, they are not likely to be permanently damaged as are many other types of apparatus, but after a break-down due to overload may as a rule be immediately restored to service.

The question of overload characteristics is an important one, and it would appear to be opportune at this time to consider special ratings for mercury arc rectifiers which would recognize the relatively high continuous capacity as compared to their overload capacity. Such data might well be included in A. I. E. E. Standards. At present a "nominal" rating which means little, is assumed in order that standard overload specifications may be met.

A limitation of the mercury arc rectifier is in its voltage regulation. There is, of course, no possibility of "over-compounding," and therefore there is a drop in bus voltage at heavy loads. This feature, however, especially in the case of street-railway loads, may be offset by scattering automatic rectifier substations about the territory served, utilizing high-voltage a-c. distribution. Such a plan would, of course, mean a relatively low load factor on each substation and, therefore, a considerably greater installed capacity would be necessary than if the apparatus were concentrated. It is probable, however, that before long, on account of quantity production and amortization of development expense, mercury rectifiers will be available at considerably lower cost than rotary apparatus, even for 600-volt service, and the excess capacity will thus be justified by the obvious advantages of small scattered substations.

It is probably going a little too far to say that the mercury arc rectifier will soon exert an influence on the much-discussed question of direct current versus alternating current for heavy traction systems. The electrification system finally adopted as a standard in this country will necessarily be capable of handling all branches of operation economically and reliably, including suburban service and "through" traffic of all kinds, over the same tracks. National standardization in this respect is nearly as important as track-gage standardization, and should rest on considerations which are broader than the economics of any one individual problem.

The chief limitations thus far with d-c. systems are not in the generation of power so much as in the flexibility of its distribution and use on the rolling stock, and with the increasing voltages mentioned by Messrs. Marti and Winograd, even though they may be practicable at the substations, problems will necessarily be met on the cars or locomotives in main motors and auxiliary facilities. Although it is of course impossible to predict what the future holds in store for us, nevertheless it may be said that the fundamental advantage of alternating current as compared with direct current in the present state of development of the art of electrification, is in the flexibility of the a-c. system, wherein it is possible on a single distribution system to operate motor cars, either singly or in multiple-unit trains up to ten or twelve cars, as well as high-speed "through" passenger trains, and extremely heavy-tonnage freight trains with concentration of 15,000 or 20,000 h. p. in a single train. This degree of flexibility has thus far not been reached with any d-c. installation yet designed, and it does not seem probable that the mercury arc rectifier can change this phase of the situation very much, especially as it is, of course, impracticable to regenerate power and feed back into a transmission system through this type of apparatus.

O. K. Marti and H. Winograd: Mr. McCurdy answered practically all the questions on interference which were raised during the discussion, and he brought out very clearly the problems involved in mercury-arc rectifier installations in connection with communication systems. I should only like to follow up one point a little further. As he states, there are also harmonic ripples present in the d-c. sides of synchronous converters, and I might point out that interference is sometimes caused by synchronous generators and condensers. Up to the present time, no definite rule has been established by technical societies with regard to the permissible volume of this interference for any kind of machine, and it is therefore difficult to arrive at a proper conclusion in regard to the permissible magnitude of the ripples. In connection with the machines which cause interference, the noise-meter and the telephone-interference-factor meter are used to obtain some quantitative measure of the interference effect. Assuming, now, that the influence of the rectifier ripples is measured by this meter, and that we allow about the same telephone interference factor for rectifiers as for other machines, a filter equipment which is not prohibitive as to cost and maintenance can probably be found, especially since the recent improvements in condensers, due to the greater demand for them for radio and for power-factor correction, have improved their quality and also made them lower in price.

In regard to radio interference, I should like to mention that even if the mercury arc should radiate waves of the frequencies used in radio communication, they would probably be shielded by the steel tank. However, it does not radiate such waves, and no difficulty has to be feared in that regard. It might, however, be mentioned that a great deal of investigating has been done in this connection in Europe, Canada, and in this country, without any influence on radio being observed.

I had intended to discuss Mr. Butcher's paper quite thoroughly, but Mr. Herz and Mr. Antoniono, whose companies have had rectifiers in operation for an appreciable period of time, gave a much better comparison of the advantages and disadvantages of mercury-arc rectifiers and synchronous converters than I would have been able to give.

I should, however, like to make some remarks regarding the first cost and the cost of maintenance, as brought out in this paper. The maintenance cost of rectifiers and their automatic equipment is less than for synchronous converters, as was proved by many comparative studies made abroad and in this country. It is unjust to base a comparison in regard to maintenance on the experiences obtained with the few early trial installations in this country, and the comparison will come to be more in favor of the rectifier as this equipment and its characteristics become better known.

The cost of an installation as indicated on the last page of Mr. Butcher's paper, giving the cost of the building and foundation as $5000 for either a rectifier or a rotary converter, cannot be correct for two reasons: First, the number of cubic feet of space required for a rectifier installation of a certain rating is much less than for a converter installation, and, since there are no heavy moving parts in a rectifier, the foundation costs practically nothing by comparison. According to our estimate, the cost of a rectifier substation would be about two-thirds the amount stated in Mr. Butcher's comparative table. Since the

heat produced by the losses in a rectifier is carried away by the water, no extensive space is required above the rectifier, as is necessary for the proper cooling of a synchronous converter. The cost of making a well in case no running water is available can be circumvented by using a recooling system, the cost of which is considerably lower than the cost of making a well as given in Mr. Butcher's paper. If the comparison had been made upon such a basis, it would have shown that the first cost of a rectifier installation compared to a converter installation for 600 volts, direct current, would be the same, or even less. There is a tendency, and I do not see any reason why it cannot be done, to increase the trolley voltage to 750, and even to 800 volts. At such a voltage the first cost of the rectifier will be less and the saving effected due to lower losses in rectifier and feeder will be extremely favorable.

Answering Mr. Clark's question, I believe the tendency toward higher voltages in Europe is accounted for by a desire to secure a higher rectifier efficiency and to reduce the distribution losses as well. In one case 800 volts was adopted in order to do away entirely with all feeders, the rectifiers working directly on the trolley line at 800 volts. The spacing of the substations is very close, being only about half a mile. The rectifiers are mounted right on the station platform, there being no enclosure other than a screen, and the transformers are mounted close to the rectifiers. In this case, almost the entire cost of a substation building and feeders was eliminated.

In answer to Mr. Lesser's question in regard to the attendance required, I should think that the same practise as applied to rotary-converter stations should be adopted for rectifiers. Due to the fact, however, that a fully automatic rectifier installation is simpler and involves less automatic equipment, it requires less attention.

In this connection may be answered the last part of Mr. Standing's question about the troubles to which rectifiers are subject. The main trouble experienced with the rectifier itself has been back-fires, or arc-backs. By improvements in the design of the rectifier and its auxiliaries, these have been practically eliminated, and when they do occur, they have no serious consequences as the rectifier can be put back into service immediately. In automatic rectifier substations they are taken care of by automatically reclosing circuit breakers.

Mr. Grotzinger made a remark about the use of rectifiers for 240/120-volt, direct-current, three-wire systems for industrial plants. There are a number of such installations in service. Since the rectifier efficiency is considerably reduced at the lower voltages, on such systems the rectifier is usually connected to the outside wires, and a balancer, which may be a battery or a small motor-generator set, is used for obtaining the middle wire.

As for parallel operation, the rectifier is far better suited for such service than a rotary converter. Rectifiers will operate in parallel satisfactorily even if connected to two independent a-c. systems having different frequencies. Should the voltage be lowered, the rectifier cannot feed back, so that one rectifier cannot affect other rectifiers operating from the same or other a-c. networks. Frequently a power company would like to operate a rectifier from 25- and 60-cycle systems during certain periods. That, again, is an advantage of rectifiers, as they can operate equally well at 15, 25, 60, or even 100 cycles. The only factor which will be affected is the size of the transformer, which of course must be dimensioned for the lower frequency. This will cause a slight decrease in the efficiency of operation at lower frequencies.

In regard to the question of whether a rectifier transformer has to be rated for a higher capacity than a transformer for a synchronous converter, and to what extent the size is affected by the number of phases, see curve No. 3 in Fig. 9 of the paper. From this curve it is evident that a two-phase transformer, for instance, has a rating of 125 per cent of the d-c. output, and about 145 per cent of the d-c. output for six-phase rectification. As a rule, because of the simplicity of the interconnections between the phases and the lower cost, three-phase transformers are used with rectifiers.

If a rectifier is operated in a place where the temperature is high, its operation is entirely unaffected, as the heat generated by it is taken away by the cooling water and therefore the ambient temperature does not matter. This is another advantage of the rectifier; one can place it in a small space and does not have to bother with ventilators and ventilation ducts to remove the heated air from the room. Incidentally, the amount of noise generated by the vacuum-pump motor is so small that rectifiers may be located in places where rotary converters would be out of question. In fact, we have rectifiers operating in department stores, municipal buildings, hospitals, and other locations where the absence of noise is of prime importance.

In reply to Mr. Waugh's question regarding the relative costs of rectifiers and motor-generator sets for 50 and 100 kw., 220 volts, the price of rectifiers would be higher. For such capacities, rectifiers would be used only if other factors, such as noise, flexibility, or operation, etc., make their application advisable.

As to Mr. Doggett's remarks, I wish to say that the comparison of efficiencies in the paper concerns 3000-volt conversion, for which synchronous converters would not be used.

Mr. Shand: Mr. Marti has referred to the difficulties of the design of transformers when used with rectifiers,—a point which was also touched upon by Mr. Herz. I mentioned in my paper some extensive work on the investigation of rectifiers and circuits, and I believe that by adhering to the principles determined, these difficulties are not great; and in fact, they have not been found so. Where complex arrangements of the transformer windings are used, there naturally will be some undesirable complications. The transformer inductance determines, to a large extent, the voltage regulation of the rectifier, and it requires careful design to obtain the proper distribution of this inductance in the windings, particularly in the cases where complex schemes of connection are used. It may be said, therefore, that there is something to be gained in the choice of a simpler transformer arrangement.

Referring to Mr. Marti's remarks of the heat-storage characteristics of rectifiers as compared with rotating apparatus, I am not sure that I am in strict agreement. It must be remembered that water is the cooling medium of the rectifier and that water has a very great thermal capacity. Some calculations on this subject made some time ago indicated that the rectifier, with its cooling water, would have a slightly greater heat-storage capacity than a corresponding rotating machine. Of course, where the anodes are not equipped with water-filled radiators, the anodes will have a lower thermal capacity.

There is probably a certain amount of general misunderstanding on the subject of the meaning of the over-load capacity of normal-rated machines. Tests have shown that a rotating machine, such as a d-c. generator or synchronous converter, will reach very nearly its maximum temperature in 35 to 45 min., so that there is no basis for the supposition that the machine can carry its guaranteed overload on account of its thermal capacity. The limitation for the continuous rating is based rather on the limitation on the current-collecting parts; that is, if operated continuously on the overload rating, the commutation limit would be exceeded and the maintenance on both commutator and collector rings would be unnecessarily high. With our present state of information on the rectifier, it does not appear to have these two kinds of limitations to the same extent, so that its application may not be made to the best advantage by directly following converter practise.

In regard to telephone interference, I believe that Mr. McCurdy has brought out a number of interesting points. As he mentioned, when rectifiers are connected to a highly inductive load, such as presented by street-car motors, the harmonic currents are reduced to a point where they do not cause any appre-

ciable trouble; but as is usual practise, where low-impedance feeders connect different substations, the differential voltage between two pieces of apparatus in different substations will produce much larger harmonics over the connecting feeder. An exposure of much less than 10 ampere-miles of such harmonic currents has been found to cause trouble in telephone circuits. It has been demonstrated both in the investigation referred to in my paper, and also in later work that telephone interference can be eliminated by installing special apparatus either in the telephone circuits or in the rectifier circuit. The practicability of the elimination of telephone interference comes down, therefore, to a question of economics, both in the first cost of apparatus, and, where installed with the rectifier, in the additional losses involved.

The comments of Mr. McCurdy on the relative advantages of 6-phase and 12-phase rectifiers are not borne out in the experimental values of telephone-interference-factor which he has obtained from these two types of apparatus. It may be noted that the wave shapes of rectifiers under load are such that the advantage of the 12-phase connection will be very much reduced on account of the effect of overlap which produces further variations of voltage fluctuation but which do not occur at no load.

C. A. Butcher: It is seldom required that converters of different frequencies be operated in parallel although this is being done very satisfactorily. On the Edison system in Chicago, 25-cycle and 60-cycle converters are operated in parallel on the d-c. bus with little or no apparent difficulty.

There is something to be said about rectifier development apparently having been on a more rapid scale in Europe than in America. A reason for this probably lies principally with the rates of development of the central-station industries in the two countries.

The central station industry had its birth in this country in the three-wire d-c. system. This was quickly followed by the a-c. system, which discouraged the installation of numerous small isolated plants. Following later, the development of the central station in Europe was principally at 50 cycles, whereas 25 cycles was the predominating frequency in this country. The 25-cycle converter was, therefore, not in the same demand in Europe as in America and, perhaps, has never reached the same stage of perfection. In the substitution of central-station service for the isolated plant, the rectifier in Europe has been the competitor of the motor generator and the motor converter rather than the synchronous converter.

The development of the 60-cycle converter followed later and those familiar with it know that its early troubles were many. However, these have been quite successfully overcome. In spite of the remarks made about flashovers, the 60-cycle converter is a satisfactory piece of conversion apparatus. The development of the high-speed breaker, and the high-reluctance commutating pole has done much to assist in its proper performance. The operators can do well to study those features in the application of a synchronous converter which will contribute to its more satisfactory performance. Perhaps 50 per cent or more of the responsibility for the flashovers of synchronous converters is with matters of application and operation and not in the limitations of design.

The increase of voltage above 600 brings in many other problems in the way of design of traction motors, control, and distribution insulation, also the problem of using efficiently the higher voltages in congested metropolitan areas. The automatic substation, since attendance is not required, probably lowers the scale of voltages on which d-c. railways may be operated economically. There are probably any number of installations which years ago would have been made at higher voltages had not the automatic substation been perfected to the point where a greater number of substations with smaller spacing might be used without excessive operating cost.

The transformer design, which enables a rectifier designer to gain low efficiency at light loads, is also possible with synchronous converters since it is merely a matter of proper ratio of iron to copper losses.

Power-factor correction by operating rectifiers and converters in parallel in the same station,—a question was brought up by Mr. Blasser,—is probably something that has not been given a great deal of consideration. When one stops to think that the power factor of the rectifier, 93 per cent, is much better than that of the average industrial load, and that generators in our power stations are designed for 80 per cent power factor, I doubt if he will find very much to be gained by the parallel operation of converters and transformers in the same station for that purpose.

The question of reverse current at light loads merely means that the designs for interurban substations or metropolitan substations must be considered in conjunction with the a-c. supply in order to gain stability of synchronous apparatus and the system as a whole.

Operating third-rail systems with 60-cycle synchronous converters does not render the problem of flashovers more serious. If the installation is properly made, the flashovers are probably not so severe, on a third-rail system as on overhead, for the reason that the magnetic induction on the third rail on the average fault, causes the current to rise very slowly, and thus it may be interrupted by a breaker of ordinary speed before the load on the converter is such as to cause flashover.

THE APPLICATION OF ELECTRICITY IN CEMENT MILLS[1]

(NORTH)

BETHLEHEM, PA., APRIL 22, 1927

E. B. Wagner: Mr. North mentions that the main substation was enclosed in a brick building in order to protect the equipment from dust. I would like to ask how he was able to keep the dust out of the building.

He told us that he had provided the super-synchronous motor with an automatic starter. I should like to know if this is a full automatic starter; that is, does it take care of automatically applying the brake on the revolving stator so as to slow that down and bring the rotor up to speed?

W. E. North: The high-tension transformers and switching equipment were housed in a building because the combination of cement dust and water causes a lot of trouble on 110,000-volt insulators that were used for the 66,000-volt service, and although it might have been satisfactory to build an entirely outdoor station, with a little less money, we didn't believe that it was wise to take that chance since the main thing we wanted was absolutely continuous operation.

A small amount of dust gets into the building but the dry dust doesn't have nearly the same disastrous effect on insulators as cement dust coked up with water.

The automatic starters we have on the synchronous motors do not automatically put on the brakes. That has been a later development. The motors are not thrown directly across the line but are started with an autotransformer with reduced-voltage taps. I don't know on which taps they were working at present but about 40 per cent increase over the normal operating current is required for starting and the brake is put on by hand after the starter automatically throws on the field. The men operating these motors have become fairly skillful in the operation of the brake, and we can't see any rise in the power curve when the mill is brought up to speed. We allow from 15 to 20 seconds for the acceleration of the motors and it is entirely possible to operate the brake by hand to get these results.

F. C. Caldwell: I want to ask if high-tension electric precipitation devices for abstracting the dust from the air are in use at all in cement mills; also, whether the general tendency to extend the use of roller and ball bearings that is going on these

1. A. I. E. E. JOURNAL, September 1927, p. 881.

days is likely to result in their general adoption in the case of the cement-mill motors. Mr. Findlay of the Giant Portland Cement Company told me that his company has used nothing but ball or roller bearings for the last five years and they are thoroughly "sold" on the use of that type of bearing for cement-mill work; that they have had no necessity for the replacement of the roller or ball bearings, and that they would use no other kind.

W. E. North: From 1917 to 1919 we had a precipitation apparatus at our plant. It will collect the dust. The principal reason that we abandoned it is that in our particular case the gain we made was far offset by the cost of operating it. In some cases, in a new plant possibly, where the dust collector is built with the plant and designed to operate with that particular plant, you would probably have much better operating conditions. The mill in which we installed an electric precipitation dust collector was an old one and we had to put this dust collector where we had available space and it was not as efficient as it would have been if we had sufficient space to install a system of greater capacity.

In regard to the bearings, the best way, I believe, to protect motor bearings, or any other kind of bearings or any other machinery around a cement mill is not first to try to make the bearings dust-tight but to provide dust-collecting apparatus to remove the cause of the trouble. However, if that cannot be done without enormous expense, the next step is to protect the bearings. With regard to that, however, our mill is not a dustless mill and we have just installed some new 60-cycle motors there. The original installation was made in 1913 and 1914, and it was taken out the first of January this year, which is 13 years of operation.

As to the life of the bearings in these motors we would sometimes lose a bearing in 2 weeks at first but we soon remedied that. We have, for instance, one 75-h. p. motor that ran 12 years without a change of bearings. Our tube mills were driven by 150-h. p. squirrel-cage motors mounted in rather dusty places on the second floor because of lack of space on the first floor, and they were running with excessive belt tension. The bearings on these motors averaged 2 years. The average life of the smaller motor bearings; that is 25-, 15- and 10-h. p. motors driving elevators and conveyors which are usually mounted in fairly dusty places, was 1½ years. As to the vertical motors with ball and roller bearings driving Fuller mills in a coal mill, one of those never had the bearings changed. Our vertical motors with ball bearings averaged 4 years.

As to the effect of dust on the coils, we have 80 motors whose coils were never repaired, 70 motors were patched, and 10 of them were completely rewound in 13 years' service.

As to the ball and roller bearing applications on motors, I have personally no data on their life in the cement industry.

In a properly laid out plant, as a rule, the time required to replace babbitted bearings does not often hold up production very much because such repairs can be foreseen and may be made during regular repair periods.

D. M. Petty: There seems to be doubt in the minds of some people, particularly those who have not been in the steel industry to any great extent, as to why some of us in the steel industry are particularly interested in ball bearings. We know from experience in the steel industry that the babbitted bearings will be cheaper than ball bearings, so far as the cost of bearings is concerned. The reason we put ball bearings in our motors, however, is to eliminate the loss of windings due to the lubricating oil getting out of the bearings and into the windings. We found by keeping a very careful record in our own plant and by questionnaires sent out among all of the other larger steel plants where proper records were kept, that at least 75 per cent of all motor failures were due to the oil getting out of the bearings into the windings, and that is the big reason why I, personally, and the committee on which I served came to the conclusion that ball and roller bearings would be a good proposition in the steel industry. In the cement industry, motor windings are not subjected to all the hazards that we have in the steel industry. Cement itself is a fair insulator. If we could only get our motors filled with cement instead of smoke and gasses and carbons and other such things, I don't believe we would have to worry about ball bearings in steel mills. I don't see why ball bearings wouldn't work out in the cement industry, but as in the steel industry more for the sake of saving windings than for the bearings themselves.

G. M. Kennedy: I understand Mr. North to say that the 2300-volt squirrel-cage motors are manually operated and the 440-volt squirrel-cage motors are automatically controlled. I would like to ask why that is the case.

W. E. North: The 440-volt motors are thrown directly across the line simply by means of an automatic magnetic switch. The reason we have manual operation on the 2300-volt squirrel-cage motors is that quite a few of these motors were put on machines which would probably be replaced soon after we finished the reconstruction of the mill and we did not spend any more money than necessary on them.

A. J. Standing: I would like to ask Mr. North, if in the layout of a new mill today he would use 440 volts or would it be possible to go to 2200? What I am getting at is the safety of the men around the plant.

W. E. North: I believe I would put in 440 volts. That, of course, is a matter of personal opinion, I believe that 440-volt equipment with the proper apparatus can be made safe enough not to interfere with safe operation. For 14 years we operated at Coplay with 550 volts and we did not have any serious accidents to our operating force due to the voltage. We have had a few slight accidents due to flashover on opening switches. On the 440-volt apparatus that we have now, the starting equipment is totally enclosed; there is nothing exposed whatever on the whole layout. I think I would use 440 volts in preference to 220 volts for small motors on account of the feeder conditions, and 2200 volts for larger motors.

John Grotzinger: I am particularly interested in the application of the super-synchronous motor to tube-mill drives as the application of synchronous motors to heavy mill drives in the rubber industry, with which I am connected, has been a feature of the past two years.

Can Mr. North give us the torque characteristics of his super-synchronous motor, particularly the pull-out torque?

Is excitation furnished from a belted exciter or an external d-c. system and what method is used to apply the field at the proper time during the starting operation? Is a frequency relay used for this purpose or current lockout in combination with a definite time relay?

W. E. North: These 600-h. p. super-synchronous motors I was speaking about drive tube mills which require a running load of about 425 to 450 kw. We have never made any tests on the starting torque or the pull-out torque on those mills. Since the load is applied by means of a brake the principal starting consideration seems to be the period of acceleration. After the motor is up to speed we begin to apply a manually operated brake and it is possible to hold the current constant at full-load running value, if sufficient care is exercised in tightening the brake. We never have had any trouble with starting and therefore have never made any tests on the starting torque of those motors.

The excitation is supplied for three of these motors by a motor generator or exciter set. I cannot give the exact details of the relays used but to the best of my recollection, current-lockout in combination with time-limit relays are used.

F. E. Fairman: In connection with the operation of these super-synchronous motors and also the other 2300-volt switching equipment, I should like to know just what experience was had with the operation of auxiliary devices and auxiliary contacts for the field contacts on the synchronous motors, first, with dust

in the substations, and just what steps were found necessary to be taken in maintenance, cleaning and the like.

H. H. Leh: We have noticed that when surges occur on the line feeding our plant the undervoltage release on our super-synchronous motor opens quite frequently, throwing the motor off the line, whereas the induction motor in the plant keeps in continuous operation without the undervoltage release opening. I should like to know, if possible, whether this is an inherent characteristic of the motor or if it is only due to the design of the undervoltage releases.

Aubrey Smith: Relays are available which can be used to prevent the disconnection of a synchronous motor from its source of power by voltage dips which are not too great in magnitude nor too long in duration. Ordinarily the lower the voltage dip, the shorter the time during which synchronous operation of the motor may be maintained and vice versa. The degree of continuity of service which can be secured in any given case by use of such relay equipment depends more upon the characteristics of the synchronous apparatus than anything else. General-purpose synchronous motors, for instance, are available which will carry their load operating as induction motors for several minutes, without over-heating, at a slightly reduced speed. On the return of voltage to its normal value, these machines can be made to come up again to synchronous speed and operate as synchronous motors. Of course, in such cases control equipment must be provided which will attend to the removal and re-application of the field when the proper rotating speed of the machine is reached.

Installations making use of the control principles and equipments mentioned have been made in various places and in various industries. Such relay equipment is effective in increasing the continuity of service, especially if line disturbances are not too violent in character. If it is known at the time of planning the new installation that the source of power will be subject to momentary voltage dips, plans should be made at the outset to equip the apparatus with relays designed to sustain synchronous operation as long as possible.

W. H. Lesser: I can give some experience about that, too. We have in operation at one of our collieries a new system of preparing coal known as the sand-flotation process. Each time there is a surge in the voltage or an interruption in the power, this apparatus stops and it takes about half an hour to agitate the sand again. We have sixteen motors there and the control boards are all in one room, and every time we have a surge on the line the whole plant shuts down. Mr. Lloyd looked over the proposition and we ordered a master control panel for this installation, with a time relay on it. We set the relay for 4 sec. which holds the motors on the line during the surges.

There is another point I would like to ask Mr. North about. Do you have any trouble in the operation of the super-synchronous motor; that is, with flashovers and things similar to that?

W. E. North: No, these motors have been running continuously since they have been put in. The only trouble we have had, has been on account of misalinement of a flexible coupling. That was not the fault of the motor and it was remedied within a few hours.

W. E. Lloyd: A few years ago when the interconnection system in this territory was being built and surges were comparatively new to the customers now on this system, the tripping off of apparatus, either synchronous or induction, due to the low-voltage release was very common. We advocated either a time delay on the low-voltage trip or removing the low-voltage trip entirely, that being dependent upon the particular operation. We went through the same conditions in our power stations; fans and pumps, and other auxiliary apparatus would trip off during these surges, which we could not afford because it meant an extended interruption of many minutes rather than one minute. So we have taken off the low-voltage releases in our power stations; many of our customers have taken them off.

I feel that the super-synchronous motor is a new piece of equipment. We, as well as the customers, are feeling our way, but actually I think the time will come when we shall treat the super-synchronous motor from a low-voltage-release standpoint just as we now treat the induction motor; that is, put on an adequate time delay to hold that motor on the line during surges, allowing it to trip clear if the voltage goes entirely off for, say, half a minute or a minute, or else take it off entirely in case the power fails and rely upon the operators to clear the switch and have it cleared before the power comes back on.

In connection with the dust problem Mr. North told how he housed his equipment in a building. We can't very well house our incoming transmission line in a building and we have to fight a problem of dust on the insulators. Of course, we might run the incoming line for the last half mile in a 60 kv-a. cable, but it has not been done to date. It was our practise several years ago to wipe off the insulators every week on the last few towers adjacent to each cement mill. This worked only fairly well. We had no definite plan for changing these insulators and after a protracted dry spell followed by a light rain or a fog, we invariably had a number of insulator failures caused by leakage over the surface of the insulator due to cement dust and collection of the moisture. If we were fortunate enough to get a real heavy rain following a dry period, that heavy rain usually washed off the insulator dust sufficiently so that no trouble was encountered. Our recent experience has been to change these insulators on the last three or four towers of the line going into the cement mill every six months. The insulators further back on that line will be changed probably in periods from two to five years, depending upon just how much precipitation of dust there is on the insulator. These insulators were taken down every six months, scraped, and then finally scrubbed with a weak solution of hydrochloric acid and water, after which they were tested and if good were put into service again. It was a rather expensive proposition to scrub and clean those insulators. In the last two or three years we have been taking hot paraffin and painting the insulators with a brush. It does not affect the insulating quality at all, and when they are taken down we simply dip them into a bucket of boiling water and it melts off the paraffin and along with it comes the cement dust, and the insulator is ready to go back into service again.

Mr. North speaks about the 66,000-volt transformers which he has installed at his mill. I want to mention the reliability of that transformer. We have at least 250,000 kv-a. of this type transformer in service on the system, either our own transformer or customers', and to date we have not experienced a single failure. When I say that, I want to qualify it in this way: We have had bushings fail, but that is an attachment which can be replaced promptly and stock units are always available. We have had winding failures, where a short circuit occurred on the low-voltage side and the switching equipment did not clear the trouble, but we don't consider that an inherent defect in the transformer. So that I believe Mr. North and every one using this particular transformer at this particular voltage is going to get excellent service from the unit.

Mr. North, in speaking of his load factor of 88 per cent, reminded me of a cement mill which is using rotary converters of 4000-kv-a. capacity. They run a load factor for the month as high as 96.8 per cent at unity power factor. It was very interesting to see the operators in that substation regulate their load. They would go to the lighting switchboard and open and close a knife-switch and by a series of flashes they would signal to a motor tender out in the mill and he would merely drop off one motor or two motors, and they would thus maintain a constant load of 4000 kv-a. hour after hour.

O. S. Clark: I wonder if Mr. North has found it to be an economical proposition to install lead distribution feeder cables underground rather than in conduit. Of course, it is cheaper to install a cable underground without the conduit, but it is also

much more expensive to make repairs, and there must be a balance some place, depending upon the extent of the distribution system. I would like to hear from Mr. North on that.

W. E. North: Before putting in the armored lead cables, we got complete prices and cost data on what the cost would be for the installation of lead cables in conduit. Ours is an old mill and if we put in conduit we would have a great number of bends and in many places we would not have room to put in the conduit.

To reduce repairs we have been liberal in our selection of cables. We use cables with 5000-volt insulation for 2300-volt service and the capacities are ample. On lead cables buried in the ground we use 70 per cent of the underwriters' rating in calculating the capacity of the cable, because we believe that many failures in varnished-cambric-covered cable come from a gradual baking out of the varnish which settles to the lower part of the cable, and if the cable is never heated failures are not so frequent. I don't know what the economy would be in a plant where you had plenty of room to put in the cable ducts but in our particular case it would have been rather expensive to attempt to put in any kind of a duct system on account of the numerous manholes we would have to put in. We would have had 6 bends in one run of 400 ft.

Regarding lead cables and open or closed ditches, our experience has been just the reverse of the one mentioned, about overheating of the cables. Of course, we were fortunate enough not to have to run the main feeder lead cables near the kilns. All of the cables in the ditches are separated about 6 in. apart and clay or sand is put in to keep a cable, if it flashes over, from passing the trouble to the other ones. During our construction work some workmen doing concrete work near the cables built a fire to thaw a frozen water pipe, not knowing the cables were near. The fire was about 2 in. from a cable. In very short time the cable burned through and although there was another cable 6 in. away it was not damaged. This, I believe, justifies the use of sand between the cables.

J. T. Waugh: In discussing Mr. North's paper, I might say that, the electrical distribution systems in a wet-process mill and in a dry-process, are identical.

One type of construction, for a low-tension transformer station, that has successfully coped with the dust problem is based on the elimination of exposed leakage surfaces.

Where radiant heat is exceptionally high, the use of ventilated cable trenches with the omission of sand has been found satisfactory.

Both air-break and oil-immersed starters have been used and the results are still open to controversy. In a coal mill, however, it is important to eliminate all air contacts due to the ever prevalent inflammable pulverized coal dust and its potential explosive properties, if the proper amount of oxygen is supplied by a sudden gust of wind, and proper care has not been exercised in keeping the place clean.

In further answer to the question of the gentlemen who asks how to take care of dust in a high-tension transformer station already built, I believe the permanent sealing of all windows and the use of louvers covered with muslin will greatly tend to minimize the dust menace. In such a transformer station in the heart of a cement mill, where the above ventilation is used, shut downs for the purpose of cleaning insulators have been practically eliminated.

F. A. Scheffler: I would like to disabuse the minds of some in regard to the statement that there is a possibility of frequent explosions in cement plants. That is altogether up to the cement operating force and is a question of house cleaning. If the cement companies keep their coal mills clean and not abuse the pulverizing equipment, they will have no trouble whatever from explosions.

Discussion at Pittsfield

NOTES ON THE USE OF A RADIO-FREQUENCY VOLTMETER[1]

(Goodwin)

Pittsfield, Mass., May 25, 1927

L. T. Wilson: It has been mentioned that this meter takes from 2 to 8 milliamperes, and that a displacement current flows between the shields of the same order of magnitude. It was not specified in that statement that, that charging current is of the same order of magnitude as this 2 to 8 milliamperes only at 1,000,000 cycles. Of course, at any frequency lower than that, the charging current is proportionately lower, and down at very low frequencies, it is entirely negligible.

P. A. Borden: Mr. Goodwin states that in using the instrument he has described, it becomes necessary to get the voltage at the terminals of the instrument to be the voltage which it is desired to measure; and in this regard its application does not differ from that of any other voltmeter. To obtain this object he suggests what he has styled a "point source" of voltage, which is very nicely worked out on high frequency circuits. Without having had the opportunity to fully study the circuit, my question in this regard is,—can that arrangement be applied to commercial frequencies? If so, it would be very useful in measuring small voltages, and potential differences across circuits where a very small amount of power is available. I refer to circuits where the power consumption of the instrument compared with the power available in the circuit is so great that the ordinary instrument would disturb the value of the quantity under measurement. For example, in the determination of the volt-ampere consumption of the voltage coil of a watthour meter, current and voltage being measured simultaneously, it would be very valuable if the "point source" of voltage could be applied in the measurement.

H. M. Turner: Mr. Goodwin mentioned the fact that it is desirable to have a fairly large ratio between the currents I_1 and I_2 of say 10 to 1. The advantages are that the current amplitudes may be easily controlled by adjusting C, (Fig. 3 of the paper) without changing the oscillator coupling and that when tuning the measuring circuit to resonance the reaction on the oscillator is usually negligible.

I have used this method in the laboratory and find it convenient and satisfactory for measuring circuit constants.

W. N. Goodwin, Jr: Mr. Borden asks whether the "point source" of electromotive force could not also be applied advantageously to low-frequency measurements. What I termed a "point source" of electromotive force was provided as a means for obtaining a source of electromotive force which for all practical purposes was free from inductance. To obtain this at radio frequencies, it was found that the voltage drop across a high-resistance wire of very small dimensions gave the desired results.

On low-frequency circuits a somewhat similar method is often used in practise in which a low voltage is obtained from a higher one by means of the well-known voltage divider. In this case, however, there is no advantage in using what I have termed a "point source," since the ratio of reactance to resistance can readily be made negligible without special reduction in dimensions.

The method described, either for low or for radio frequencies is not intended for the measurement of unknown voltages, but for establishing a voltage for use in measurements. The voltage can, of course, be adjusted to a definite value by knowing the value of the resistance and that of the current passing through it.

I wish to thank Mr. Wilson for calling attention to the fact

1. A. I. E. E. Journal, May, 1927, p. 487.

that the value of the charging current given for the shields is for frequencies of the order of 1,000,000 cycles. This was inadvertently omitted from the text.

CALCULATION OF MECHANICAL FORCES IN ELECTRIC CIRCUITS

(DWIGHT)

PITTSFIELD, MASS., MAY 25, 7927

V. Karapetoff: Professor Dwight's equation (5) may be deduced directly from the general formula (2) for the mechanical force. Let the return conductor be a concentric cylinder of radius b. Let the virtual deformation of the given conductor consist of an axial lengthening of the portion of radius a_2 by an infinitesimal amount $d\,s$ and of a corresponding shortening of the portion of radius a_1 by the same amount $d\,s$. The tapered portion is supposed to move bodily without a change in shape. The inductance of a concentric cable, per unit length, is of the form,

$$L = 0.05 + 0.2 \text{ logh } (b/a) \quad \textbf{(A)}$$

in perms per cm. length[1]

Therefore, the net increase in the inductance is

$$d\,l = 0.2 \,[\text{logh } (b/a_2) - \text{logh } (b/a_1)]\; d\,s \quad \textbf{(B)}$$

Substituting this expression in Dwight's equation (2), his equation (5) is obtained. Therefore, equation (5) is valid so long as equation (**A**) for inductance is valid. The radius b of the return conductor does not enter into the result.

When considering the relationship between an electric current and its magnetic flux, it is safer to start with the universal relationship, which holds true at any point and is expressed by the familiar differential equation $u = \text{curl } H$, where u is the current density.[2] The difference between a solid and a liquid conductor comes in the boundary conditions in the integration of this equation. For a solid conductor, the boundary surface is fixed and the component of the current density normal to it must be equal to zero. With a liquid conductor, the shape of the surface depends upon the magnitude of the total current and its distribution. Because of the pinch effect, the usual hydrostatic conditions must be satisfied at each point within the liquid.

This means that, for each infinitesimal volume taken within the conductor, the forces acting upon it must be in equilibrium. These forces are the resultant pressure exerted by the remainder of the liquid, the weight of the element, and the force between the current and the magnetic field.

E. H. Dodge: I have quite recently performed some experiments concerning forces acting on a liquid conductor with currents as high as 1500 amperes.

When a right-angle trough containing mercury has a current of 1000 amperes flowing, there is a movement in the liquid as shown in the accompanying Fig. 1. The direction of motion is from B to A and the level at A is about ¼ in. higher than the remaining liquid.

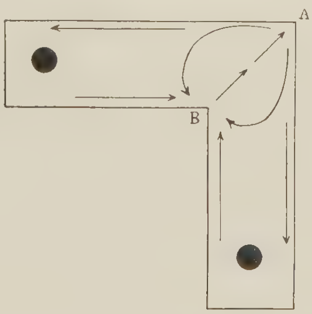


FIG. 1

If a straight trough with a constriction is used, there is a pronounced flow away from the constriction, as shown in the accompanying Fig. 2. There are also eddies at the constriction. There is a swirling motion at the electrodes accompanied by a marked depression. As the current changes direction by 90 deg., the filaments carrying current stretch out and form this depression. Within the constriction, an interesting phenomenon occurs. With 1000 amperes, the mercury level rises at the center and falls at the edges, as if the mercury were trying to crowd together to form a circular cross-section. Just before the circuit was ruptured with 1450 amperes, the level decreased.

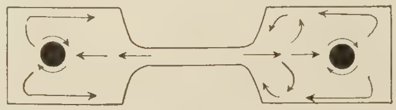


FIG. 2

The rise in level would seem to be due to the hydrostatic pressure which acts radially, and has been given by Dr. E. F. Northrup as $p = \dfrac{I^2}{100\,\pi\,R^4}\,(R^2 - r^2)$ dynes per sq. cm. at any point r cm. from the axis of a conductor $2\,R$ cm. in diameter.

The decrease in level might be explained by the action of the longitudinal thrust or the taper force which tends to drain the mercury from the constriction and thus decrease the level.

The total thrust on a vertical plane omitting the effect of gravity has been given by Dr. Carl Hering as $T = \dfrac{I^2}{200}$ dynes. This is obtained by integrating the above expression given by Dr. Northrup. This expression is independent of the size of the conductor: consequently, the thrust on a vertical plane due to the radial force is the same, regardless of the size of cross-section. With this in mind, it seems very reasonable that the rupturing of the circuit is caused by the taper force which has been given by Dr. Dwight as $F = \dfrac{I^2}{100} \text{ logh } \dfrac{R}{r}$ dynes.

A few simple calculations will bring out the differences in pressures. With a conductor carrying 1000 amperes and a cross-section with a radius which varies from 1 cm. to 6 cm., by Northrup's equation, the hydrostatic pressure at the center of the small section = 3180. dynes per sq. cm. which is equivalent to 0.0461 lb. per sq. in. and the pressure at the center of the large section = 89. dynes per sq. cm. which is equivalent to 0.00130 lb. per sq. in.

The total thrust on a vertical section by Hering's equation is $T = 5000$ dynes and equivalent to 0 0112 lb. which is the same for the large section and the small section.

Finally the taper force from Dr. Dwight is

$$F = 17900 \text{ dynes or } 0.0402 \text{ lb.}$$

Thus we see that the taper force is greater and seems to substantiate the assertion that it causes the circuit to rupture. The taper force becomes greater and greater as the small section becomes smaller before the rupture of the liquid conductor.

H. B. Dwight: In my presentation of this paper, I made the statement that equation (5) for a conductor consisting of two long uniform parts of different diameters, joined by a tapered part, can be derived by differentiating the well-known formula for the self-inductance of a long, uniform, round wire. This

1. V. Karapetoff, the Magnetic Circuit, p. 190.
2. See, for example G. W. Pierce, Electric Oscillations and Electric Waves. p. 370; M. Abraham, *Theorie der Elektrizitat*, 1912, p. 220.

derivation shows that the two long parts do not need to have the same axis so long as they have parallel axes, and the shape of the tapered part does not matter.

Such a derivation, however, does not apply to the interesting case described by Mr. Dodge, where the two long parts of the conductor have the same diameter and are joined by a double taper, or contraction. Formula (**A**) of Professor Karapetoff's discussion cannot be applied to the minimum diameter of the contraction, but only to a long uniform conductor. Therefore, in order to show that equation (**5**) applies to each of the closely adjacent tapers of the contraction, some other derivation, such as the one given in my paper, is necessary.

It has not been shown, and it does not necessarily appear, that any use of the equation u = curl H gives greater safety in calculation than the methods followed in my paper.

While it has not been uncommon for mercury circuits of small cross-section to be broken by electric currents of the order of 100 amperes, the observation in detail of the progressive steps of the phenomenon and the description of the swirling of the liquid which carries an electric current have only rarely been made since Dr. Carl Hering described them. Such observations require a large section of liquid conductor and from 1000 to 1500 amperes. Accordingly, Mr. Dodge's experiments should be of interest to physicists and to designers of electric furnaces. In determining the swirling motion of the liquid, he used heavy floats which extended deep into the liquid, since surface tension prevented the motion from being shown by sprinkling dust on the mercury. When the circuit was broken, it continuously came together and broke at the rate of several times a second.

I agree with the statement in Professor Karapetoff's paper, that Dr. Hering's work on electric furnaces and liquid conductors was of great value, but that his experimental observations are in agreement with the usual methods of calculating the mechanical forces associated with electric currents, and do not require new methods of calculation.

DEVELOPMENT OF AUTOMATIC SWITCHING EQUIPMENTS IN THE UNITED STATES AND EUROPE

(DeGoede)

Pittsfield, Mass., May 28, 1927

Chester Lichtenberg: Since its development in 1914 the automatic station has been a very interesting topic to electrical engineers. The development has been very rapid. For example, in the United States today more than one-third of the entire switchboard output of the large manufacturing companies is automatic switchboard equipment for power stations and substations. Our records indicate that over 2,000,000 kw. of rotating apparatus are under automatic control and over 6,000,000 kw. of feeders and transformers are in automatic station service.

It has been thought that the development of the automatic station would make the attendants more mechanical. This has not been the case. Instead, the personnel of the operating companies who care for automatic stations have been required to use a greater degree of intelligence than those who attend the usual type of substation. It should not be thought, however, that the automatic station is an intricate or complicated collection of devices. It is not. It is a very simple combination of devices quite well known in the control art but so skilfully connected one to another that they perform functions heretofore delegated to human beings. When one considers the problem, this is as it should be because human beings are relatively slow to respond, while the changes in the electrical circuit take place with extreme rapidity. The ordinary human being responds to an impulse in about one half a second while the ordinary electrical device will respond to an electrical impulse in one-tenth or even one one-hundredth of this time.

Sometimes it is thought that the installation of automatic stations will require the engaging of skilled personnel for their maintenance and operation. Experience has indicated that this is not the case because as before stated the equipments consist of quite common control devices although there are more of them than in the usual manually operated station. Operating companies have demonstrated that they have in their employ many who can successfully install, maintain and operate automatic stations.

Besides, the manufacturers have found that some of the operating companies have employees who can and do suggest improvements in the schemes of operation as a result of their practical experience.

Load-limiting or load-shifting resistors are almost always discussed when automatic stations are considered. These resistors have three functions;

1. To prevent the flow of excessive current between an oncoming machine and the bus.
2. To limit the drain on a machine for continuous service.
3. To shift to adjacent machines the load from a machine which might be overloaded.

Each of these functions is quite important. However, the importance varies with the application and with the type of transforming apparatus. Primarily, load-limiting or load-shifting resistors assist in maintaining service under unusual operating conditions and find here their most advantageous application.

H. S. Knowlton: I should like to ask Mr. Lichtenberg to say a few words about the training of men to maintain and inspect these automatic stations. Probably the designing engineers have provided very thorough instructions in printed form, but is there not a great gap between the ability of the designing engineer to comprehend the details of these automatic plants and that of the average operating man?

K. K. Palueff: It seems to me that the automatic substation has two very important characteristics. First, that there is no need of technical knowledge or training on the part of the operator; and second, that it makes small installations more economical.

The automatic substations will enable us to electrify small waterpower systems. I should like to add that in this country, particularly, the supply of peat was entirely neglected for the reason that the main problem connected with the development of peat was the impossibility of transportation. Peat made in such a manner as to withstand transportation becomes absolutely uneconomical. It seems to me, therefore, that the automatic stations may permit exploitation of the peat bogs in this country as well as in Russia to a far greater extent than at the present time.

E. deMulinen (by letter): Mr. DeGoede mentions that the first trial installations of automatic switching equipment were not made in Europe until 1921-22. I should like to mention that an automatic converter substation in Basel (Switzerland) has been in successful operation since 1918. Mr. DeGoede states that the development in Europe was forced by post-war conditions, but the actual development of automatic equipment was started during the war on account of shortage of labor.

Mr. DeGoede mentions that load-limiting resistors are not much used in Europe. It might be said that a drooping characteristic is used in most of the European substations for traction purposes, resulting in a great flexibility in load distribution between the different substations. This scheme protects the converter from high overloads and assures continuity of service without destroying a considerable amount of energy in load-limiting resistors. In this country, about 90 per cent of the traction substations use compound-wound machines which require load-limiting resistors to give the system some flexibility, but when laying out a new system, it will always be found that a drooping characteristic will give the most economical results.

In this respect, it may be of interest to note that in one of the most recent automatic substations in Chicago,—the Grimm Avenue Substation,—no load-shifting resistors are used, as the inherent voltage characteristics of the machines in this substation do not require such equipment.

In saying that automatic vacuum control is not generally furnished with the European automatic rectifier equipments, Mr. DeGoede doubtless refers to the first trial installations. After considerable research, Brown, Boveri & Co. has succeeded in bringing out a most reliable vacuum control which has been in commercial use since 1923 and supplied with each automatic rectifier equipment. This type of automatic vacuum control is used with over a hundred automatic rectifiers in Europe and in eight automatic rectifier substations in this country.

A. H. DeGoede: Mr. de Mulinen states some of the reasons why load-limiting resistors are in such little use in Europe. It might be said that the service conditions in the United States are usually much more severe, and in many instances it has been proved that during periods of heavy load it was not possible to keep a machine with drooping characteristics on the line, making it necessary to add load-limiting resistors to maintain service.

I was familiar with the fact that the Brown Boveri Company has equipped its automatic rectifier substations with automatic vacuum control during the last two years. However, as stated in my paper, this is still not generally furnished by most of the European manufacturers, while the American practise considers it an essential feature for full automatic operation.

The remarks of Mr. Lichtenberg supplement my paper on some interesting points. Many other points might have been treated more broadly, but in order to keep my paper within bounds, I have only endeavored to give a brief outline of the main advantages of automatic switching equipments, and of what has been accomplished along this line.

INSTABILITY IN TRANSFORMER BANKS

(Gould)

Pittsfield, Mass., May 28, 1927

V. M. Montsinger: I was very much interested in Mr. Gould's paper because it gives a possible explanation of the same kind of phenomena that I observed on some single-phase transformers a few years ago.

In 1914, I presented discussion for a series of papers on transformer connections, etc., and in this discussion, showed how condenser capacity, connected either across an opening in the delta of a Y-delta connected bank, or across the legs of the delta, intensified the harmonic voltages. Fig. 4, as given in Part I of the A. I. E. E. Transactions, for 1914 p. 782, shows that at about 45 or 50 kilolines per sq. in. core density, the harmonic voltages suddenly increases to 200 per cent of the fundamental voltage. Upon further increasing the density, the harmonic voltage decreases and then increases again; in fact, as the core density increased, there were three points at which the harmonic voltages were intensified.

Fig. 6, shown on p. 783, gives results of similar tests made on a three-phase core-type transformer, and these curves demonstrate that no intensification of the harmonic voltages occurred at any point as the core density was increased—the maximum intensification being in the order of 15 to 20 per cent of the fundamental.

One point I wish particularly to emphasize is that while we have these dangerous harmonic voltages in single-phase transformers, we do not have them in three-phase core-type transformers. The reason for this obviously is due to the fact that in single-phase transformers, the third harmonic voltages in the three legs, which are in phase and flowing towards the neutral of the "Y" connection, have a return path through the iron core leg external to the windings; while in three-phase core-type transformers, the harmonic voltage flux must return through the air.

I should like very much to have Mr. Gould's comments on how this difference in phenomena between single-phase and three-phase core-type transformers lines up with the conclusions that the contributing cause of this intensification is leakage reactance.

K. E. Gould: I have done no work with the three-phase transformer, and the present paper considers only three single-phase transformers star-connected. The statement that the leakage reactance of the transformer windings is not a contributing factor in the instability is based on the fact that in changing the capacity from the secondary to the primary, there was practically no difference in the instability which seemed to me conclusive evidence that the leakage reactance is not a contributing cause.

This statement that leakage reactance does not cause instability, was made particularly in consideration of work that Mr. Shaw did at M. I. T. in 1924. He gave a very good explanation of the instability, showing that there were two conditions—two points at which the transformers could operate—due to the interaction of the capacity, and the leakage reactances of the transformer windings, particularly in the Y-delta case, where the capacity is inserted in one corner of the delta. However, as soon as it was discovered that the instability still existed with only the iron-core reactor in parallel with the capacity, it seemed evident that the instability was not due to what Mr. Shaw called a resonance effect between the capacity and the leakage reactance of the transformer windings.

REDUCTION OF TRANSFORMER EXCITING CURRENT TO SINE-WAVE BASIS[1]

(Camilli)

Pittsfield, Mass., May 28, 1927

Aram Boyajian: For the benefit of those who are not intimately familiar with transformer problems I wish to say that the reduction of core loss and exciting current to a sine-wave basis is not quibbling over laboratory precision. The reduction of the core loss to a sine-wave basis involves wave-shape errors of from zero to 20 per cent, and the reduction of exciting current to a sine-wave basis involves errors of from zero to 50 per cent. The leading manufacturers of the country use methods to reduce core loss to sine-wave basis, and possibly some of them use methods to reduce the exciting current also to sine-wave basis. These methods greatly lessen but do not completely eliminate the possible errors mentioned, due to the fact that the bases of all the methods used in the past have been imperfect. Mr. Camilli therefore has undertaken to develop methods which will have a better basis and will be entirely reliable. I think he has succeeded surpassingly well.

K. K. Palueff: With the tests made by various manufacturers under different conditions, it is impossible to adjudge the comparative characteristics of different transformers, and it seems to me that the methods described by Mr. Camilli will give a very fine basis on which to decide whether the magnetizing current really is 2 per cent or 4 per cent.

I should like to take exception to Mr. Camilli's statement in the first paragraph of his paper wherein he says that the testing facilities, in regard to the capacity of the generators, are not increasing in proportion to the transformer kv-a. capacity. That isn't our case here in the General Electric Company. For the last five years, our testing capacity in generators has increased from 3000-kv-a. to 25,000-kv-a. units, and at the present time we are equipped to test the largest transformer we have yet built, or are going to build for several years to come, with a generator which will give very good agreement with that of the perfect sine-wave generator.

1. A. I. E. E. Journal, September 1927, p. 892.

Discussion at Summer Convention

THE PHYSICAL NATURE OF THE ELECTRIC ARC

(Compton)

Detroit, Mich., June 21, 1927

Joseph Slepian: There is hardly a scientist on whose work I lean more than Professor Compton.

I remember as one of the best of Professor Compton's papers the one on the theory of the arc which he gave in the *Physical Review* in 1923, in which he so ably defended the thermionic theory which he has discussed tonight. Today, however, Professor Compton apparently feels that perhaps this theory may not always hold after all.

Remarkable also have been his papers on abnormally low-voltage arcs. The first deals with the theoretical difficulties, almost proving that an arc with a voltage less than the ionizing voltage of the gas is impossible. A later paper, however, demonstrates the existence of arcs with voltage less than the ionizing potential but greater than the resonance potential. Then followed a paper showing that where arcs with voltages lower than the resonance potential had apparently been obtained, oscillations had been present which momentarily would raise the voltage above the resonance potential. Then came still another paper showing that arcs with total voltage less than the resonance potential were possible under suitable conditions.

Another paper which I found exceedingly valuable, stimulating and instructive, is that one on the Mobility of Ions in Discharges in which he very boldly sets out to calculate the ways in which ions will move in gases of considerable density under the action of the electrical fields, taking account of various kinds of collisions which electrons can have with molecules. This was an exceedingly difficult problem, and I marveled that anyone had the temerity to tackle it. Yet with a few skillful manipulations and ideas, Professor Compton derived equations which are quite easy to understand and exceedingly valuable.

There are some experiences which I have had in connection with my engineering work which I think will be interesting in relation to the theory of the arc. The various theories of the cathode of the arc mentioned by Professor Compton require that a considerable portion of the current be carried by electrons leaving the cathode. The question then arises as to how these electrons get out of the cathode, as ordinarily electrons will not pass from a metal into an adjoining gas. One agency which will assist electrons in escaping from a metal is heat. When its temperature is sufficiently high electrons can pass freely out of a cathode. This is essentially the thermionic theory of the cathode of the arc, which Professor Compton advocated a number of years ago.

Another possibility which Professor Compton has mentioned is that a very high electric gradient may develop at the cathode surface in the arc a gradient so high that the electrons are pulled out of the cathode even though it is not hot enough for thermionic emission.

At the time of the experiments which I am going to describe, I, along with almost everybody else, believed in the thermionic theory of the cathode; that is, that in an arc it was necessary to have a cathode hot enough for thermionic emission. If the cathode was not hot enough for this, an arc discharge would be impossible, and if any discharge was obtained it would have to be a glow or other high-voltage form. I tried to apply these ideas to the development of the arc which follows the breakdown of a spark-gap by application of high voltage.

Since the electrodes of the spark-gap are initially cold, it seemed necessary that the discharge should start as a glow and only after some point of the cathode reached a sufficiently high temperature should the discharge change into an arc. I tried to calculate the time for the heating up of the cathode spot, and therefore the time for the flow to change into an arc, using data for the watts input at the cathode of a glow on copper obtained from other experiments. I found it would take seconds before the copper would get to the melting point, let alone a temperature sufficient for thermionic emission. But the experiment showed that the arc struck almost at once. Immediately after the gap broke down, the voltage dropped to 20 volts, which is too low for a glow.

I had been of the opinion that the cathode had to be hot in order to maintain an arc; yet here, where the electrodes did not have time to get hot, I was getting a discharge with only 20 volts. More recently, this experiment has been repeated, using the DuFour Oscillograph, and it has been found that the time for the discharge to change from glow to arc is of the order of a microsecond.

Since the cathode couldn't have become hot in so short a time, this experiment made me feel that the thermionic theory of the cathode couldn't be correct; at least not all of the time.

Another experience in connection with my engineering work which made me believe that probably the cathode didn't have to be hot was in studying the operation of switches. I have seen switches in which the arc was blown rapidly along the arcing horns operate, and examined the horns afterward, finding stretches on the arcing horn absolutely free of burning. There might be some oxidation but no evidence of a very high temperature.

This seemed strange and would be hard to explain if the cathode had to be hot enough for thermionic emission. I looked into this a little more closely, and considered the hypothesis that perhaps the arc hopped from point to point, without passing over the intervening stretch, so that this stretch might not appear burned because the arc had not actually played on it.

I eliminated this possibility by bringing the electrodes very close together, and also took photographs with a high-speed camera. I found that even at those spots where the arc had played, as indicated by the photographs, there was no burning.

A German, H. Stolt, has also carried out similar experiments, published in the *Annalen der Physik.* Stolt caused an arc to move over a cathode so rapidly that apparently there was no heating of the cathode. The claims of Stolt were criticized by Guntherschulze, who is mentioned frequently in this paper of Professor Compton's; but Stolt replied quite well to the criticism of Guntherschulze, and I believe that Stolt's conclusions are fairly well established. Stolt did get a low-voltage discharge from copper and other metals, which moved so rapidly over the copper surface that no spot of the copper surface became hot enough to melt, let alone have thermionic emission. This seemed to me to disprove definitely the theory of the necessity for thermionic emission. I have carried experiments similar to Stolt's somewhat further, and have used currents as high as 20,000 amperes; that is, I have moved a 20,000-ampere arc, over a cathode surface so rapidly that there was no melting of the copper but merely a trace of oxidation. Incidentally, the current density in these experiments was of the order of 30,000 amperes per $cm.^2$

The application of the method of energy balance at the cathode which Professor Compton has used in his paper for estimating the fraction of the current carried by electrons is certainly very interesting, and the values $f = 0.25$ to $f = 0.16$ obtained for the mercury arc seem significant. If the ionization of the gas next to the cathode is primarily due to collisions from electrons coming from the cathode, f could not be less than 0.50.

Some time ago, I suggested in the *Physical Review* that perhaps no part of the current at the cathode was carried by electrons, but that all of the current was carried by positive ions coming from the highly ionized gas next to the cathode. The cause of the high state of ionization in the gas was to be sought in the very intense energy concentration there. The values of f which Compton finds indicate that this suggestion may be near

the truth. Indeed, if a necessary correction to the energy balance equation is applied, the value of f comes even closer to zero in accordance with my suggestion. The correction is as follows. As item (1) under A, "Heating of the Cathode," Professor Compton has "By incoming positive ions, which fall through the cathode drop B_c, $(1 - f)(B_c + \phi_+)$." But all the positive ions do not fall through the cathode drop unimpeded. Some will collide with molecules and lose energy to the gas. Also, many positive ions will be reflected from the cathode thus increasing the chances of collision with molecules. Let α be the fraction of the energy acquired by falling through the cathode drop, which a positive ion, on the average gives up to the cathode. Then item (1), under A, becomes $(1 - f)(\alpha B_c + \phi_+)$.

Equation (**21**) then becomes

$$f = \frac{\alpha B_c + \phi_+ - F B_i + H - C - C' - R - E}{\alpha B_c + \phi_+ + \phi_- - F (B_c B_i)}$$

If we substitute the numerical values used by Compton we get

$$f = \frac{8.6\,\alpha - 5.5}{8.6\,\phi + 3.9} \text{ or } f = \frac{8.6\,\alpha - 6.6}{8.6\,\phi + 3.9}.$$

If we take $\alpha = I$ we get, of course, the values of Compton, $f = 0.25$ and $f = 0.16$. If, however, α is as low as 0.64 by the first formula, or 0.77 by the second formula, we get $f = 0$.

Now what is a reasonable estimate of the value of α? We may obtain some idea by determining the number of positive ions which cross the cathode space without colliding with a molecule. The electronic mean free path as given by Compton in this paper for the mercury-arc cathode is 4×10^{-5} cm. and therefore the ionic mean free path is 1.0×10^{-5} cm. On the other hand from equation (**20**) taking $-J = 4000$ as given by Guntherschulze, we find, for d, the cathode-fall space $d = 4.95 \times 10^{-6}$. The fraction of the positive ions which will have free paths greater than the cathode-fall space will therefore be

$$e^{-\frac{4.95 \times 10^{-6}}{1.0 \times 10^{-5}}} = e^{-0.495} = 0.61.$$

That is only 61 per cent of the positive ions crossing the cathode-fall space fail to collide with a gas molecule. Hence a value of α equal to 0.77 does not look altogether unreasonable.

J. C. Lincoln: At the plant of The Lincoln Electric Company, we have run across a new phenomenon which has to do with the nature of the arc and which has changed my notion of what happens in the arc. This phenomenon occurs in a device which we call an "electric torch."

The illustration herewith, shows the arrangement of the parts making up the torch. The copper electrode holder for the negative terminal is water-cooled as well as the copper positive terminal where the path of the cooling water is indicated. The copper anode has a tapered hole of the dimensions indicated on the sketch cut in it. The opening in the anode is round and the dimensions are those of a section through the center of the opening in the anode.

After the parts are set up an arc is started between the carbon cathode and copper anode by short circuiting them with a carbon pencil. While the arc is maintained, a flame projects from the anode as shown in the illustration.

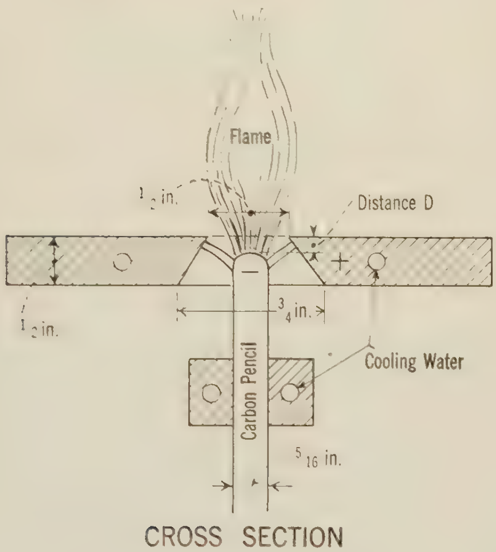
Observation of the arc shows that the size of the flame projecting from the anode is roughly proportional to the amperes across the arc, as might be expected.

Furthermore, with a given current, the flame is larger when the distance D is smaller, the size of the flame decreasing as the distance D is increased.

A change of current causes a much greater difference in the size of the flame than is caused by a proportionate change in the distance D.

The flame is apparently due to very hot carbon particles.

If the flame is cooled, carbon is deposited on the cooling surface just as it would be if the flame from a wick were cooled.



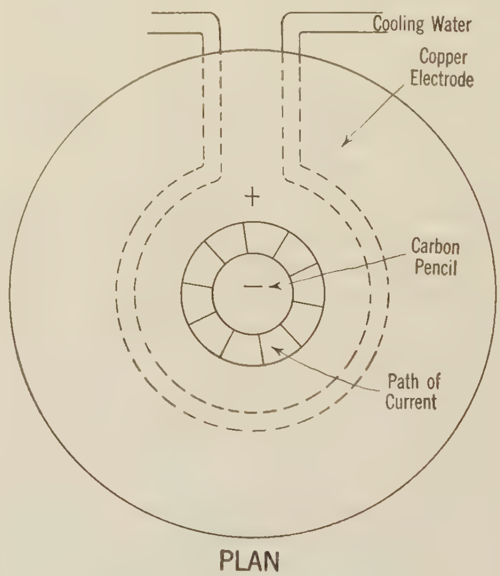


Fig. 1

A series of tests was made varying the current and the spacing D. The current was furnished by one of the company's 200-ampere, d-c. welders and was adjusted to 50, 75, 100 and 150 amperes across the arc. The distance D was adjusted to 3/16, 3/8 and 9/16 in. For the results shown in the accompanying table, the flame was above the torch, as shown in the illustration.

To determine the amount of heat in the flame, the amount of cooling water passing through the torch and its rise in temperature were measured. In the tests the initial temperature of the cooling water was 19.1 deg. cent. and 5.375 lb. per minute was used. From these measurements, the heat absorbed by the water was calculated. The rate at which this heat was absorbed was then expressed in watts. It was assumed that the watts input, minus the watts carried off by the water, equals the heat energy in the flame, and the table shows the percentages of heat in the water and the flame respectively.

The results indicate in general that the greater the current, the greater is the energy in the flame; also, that the smaller D is, the greater is the energy in the flame.

TABLE I

D in sixteenths of an inch	Amperes	Volts	Watts input	Temp. rise of cooling water, deg. cent.*	Watts absorbed by water	Percentage of heat In water	In flame
3	50	47	2350	5.9	1002	42.5	57.5
6	50	48	2400	6.9	1170	48.8	51.2
3	75	51	3820	8.9	1535	40.2	59.8
6	75	40	3750	9.9	1695	45.2	54.8
9	75	48	3600	11.9	2020	56.0	44.0
3	100	55	5500	10.9	1850	33.6	66.4
6	100	51	5100	13.9	2360	46.1	53.9
9	100	49.5	4950	16.2	2750	55.5	44.5
3	150	57	8560	18.4	3130	36.6	63.4
6	150	51	7670	20.9	3560	46.5	53.5
9	150	51	7670	23.9	4040	52.7	47.3

*5.375 lb. of water passed per min.

The table shows that from ½ to $^2/_3$ of the heat appears in the flame, and I believe that if none of the heat developed in the flame was radiated and absorbed by the copper and water, an even larger proportion of the total heat in the arc would appear in the flame.

The direction of the flame can be affected by a magnet. By presenting the south-seeking pole of a bar magnet to the arc, the flame is pushed to one side. So far as I could judge the flame itself is not affected by the magnet. The direction of the flame is a function of the current from the carbon cathode to the anode. To put it another way, the magnet had no effect on the direction of the flame except when close to the arc between the carbon and copper anode.

The current between the carbon and copper anode is effected in just the way one would expect from the laws governing electromagnetic action.

When there is no external magnetic field at the arc, the current flows radially between the carbon and the copper anode. When the arc is subjected to an external magnetic field, the current is forced to only a part of the radial path between carbon and copper and at the same time the flame is deflected so that it is more at right angles to the current.

What bearing do these results have on our conception of what takes place in the arc?

The present view is that the voltage across the arc is made up of three portions; (1) the drop at the negative terminal, which must be great enough to heat the terminal to the point where it will throw off ions readily, (2) the I-R drop due to the resistance of the gas stream between anode and cathode and (3) the drop at the positive terminal which is fixed by the nature of the material and in the carbon arc is much greater than the drop at the negative terminal. The results of the measurements would indicate that in the carbon arc there is a drop at the positive terminal that may be fixed by the nature of the material, but that this drop is not nearly so great as has been supposed. The heat at the positive terminal in the ordinary carbon arc is the sum of the heat due to the inherent drop and the heat of the flame or blast from the negative terminal. The heat due to the flame or blast has been separated largely from the inherent anode drop in the electric torch and measured. The measurements indicate that the heat in the flame or blast is greater on the average than the sum of the anode drop, the cathode drop and the I-R drop due to the resistance of the gaseous part of the arc.

I do not think it is far from the truth to say that two-thirds of the energy in the carbon arc appear as heat in the flame or blast from the cathode. The question naturally occurs—What is the nature of the flame? Two things can be said of it. First, particles of very hot carbon are shot off the end of the cathode and these draw the air with them so that the flame from a match is sucked downward through the opening in the anode when the apparatus is set up so that the flame is below the torch. The current of air was doubtless much stronger when the apparatus was turned over, for it was not possible to get the 9/16-in. reading with 50 amperes, for the arc would not persist long enough to permit of measurement of the heat.

I assumed that this was due to the stronger current of air through the opening in the anode when the apparatus was set up to take the measurements contained in the table.

The second thing is that the actinic value of the flame near the opening in the anode is very much greater than the value in most of the flame. When the flame was focused on the ground glass the image of the flame covered nearly the whole plate, but a short-time photograph showed a very small figure on the plate. The pictures were taken in 1/500 to 1/1000 sec. and at this speed, not more than 10 per cent of the flame that showed on the ground glass plate appeared on the photograph.

A picture of the flame was taken with the camera behind a piece of ⅛-in. thick pasteboard to see if the active part of the flame contained X-rays. The results were negative.

When the current was reversed in direction, the apparatus refused to work as a torch and the arc apparently tried to run up the carbon when it was made the positive terminal of the arc. This is a most noteworthy fact, for it depends on something beside the electromagnetic forces. In any piece of apparatus with which I am acquainted, the direction of motion is independent of the direction of current, for the reversal of current reverses the flux and with both flux and current reversed, the direction of motion is unchanged.

What is this blast or flame from the cathode? Apparently it is not a stream of electrons, for if it were, it would be affected by a magnetic field. At the same time it must be remembered that approximately two-thirds of the total energy in the arc appears in this flame. It is my opinion that the blast from the cathode in the carbon arc is due to vaporized carbon from the carbon pencil.

We do not know much about the latent heat of carbon, but it is possible and even probable that it is very high. If I am correct in the opinion that most of the energy of the carbon arc is expanded in vaporizing carbon from the carbon cathode and that most of the heat that appears at the positive anode is due to the solidification of the vaporized carbon at the anode, this would be evidence of a large amount of energy required as latent heat to vaporize carbon.

It is my belief that to get a more accurate conception of what occurs in the arc, we shall have to substitute the idea of the blast from the negative terminal as being the central and important thing which occurs in the arc, for the idea that there are inherent anode and cathode drops.

The tests described in this paper show that the flame is a phenomenon associated with the negative terminal.

The old way of looking at it would be to say that the inherent drop at the positive terminal was great enough to produce the heat that actually appears there. This old conception has, I think, been shown to be wrong by these tests.

The old idea was that the current passed across the arc in a solid stream and that a cross-section of the current in the arc would be a circle.

The experiment with the torch, as well as some others not described, indicate that the core of the arc is the blast from the negative terminal and that the current flows outside of the blast and that the section of the current across the arc would be an annulus and not a circle. In such a cross-section, the inner circle would be the cross-section of the blast from the negative terminal and the annulus outside of this inner circle would be the cross section of the current. There is no doubt that this is the true picture of the cross-section of the current in the case of the torch, and I believe it is the true picture in any carbon arc.

P. P. Alexander: I should like to ask Professor Compton

to say a few words about the ionizing potentials of different gases. These are well known at ordinary temperatures, but at the temperature of the arc core, apparently, they are entirely different. For instance, the ionizing potential of nitrogen at ordinary temperature is something like 11 volts; at the temperature of the arc core, it appears to be several hundred times less.

I should like to ask Professor Compton if experiments have been made to determine the various ionizing potentials at high temperatures, because knowledge of these potentials is quite essential to the correct interpretation of arc phenomena.

V. Karapetoff: Dr. Compton's paper is mainly concerned with simple, steady arcs, and it is only right that an involved phenomenon should first be studied in its simplest form. In practical applications, we have mostly variable arcs, and our problem is two-fold: (1) To make an arc as steady as possible; for example, in arc furnaces, in electric welding, in arc lamps, rectifiers, etc.; or else, (2) to make an arc as unstable as possible so as to extinguish it quickly; for example, in switches, spark-gaps, relay contacts, flashovers, etc.

In either group of problems, it is of importance to know the factors which contribute both to the stability and instability of an arc, so as to intensify the desirable factors at will. This means that engineers will have to pay more and more attention to the physical nature of the arc, and Dr. Compton's paper, with its references to literature, should prove a valuable introduction to the subject as well as a guide to future investigators.

Dr. Compton quotes several empirical equations for the observed relationship between the voltage and the current in a steady arc. In a transient arc, or spark-over, both the current and the voltage are functions of time, and the apparent total resistance of the arc is variable. Dr. Max Toepler[1] has proposed the following function for this resistance:

$$R_t = k\,F / A_t \qquad \textbf{(a)}$$

Here k is an empirical constant, F, the length of the arc, and A_t the total quantity of electricity which has passed through the arc from the instant $t = 0$, when it was struck, to the instant t under consideration.

For a transient arc, there is some reason for Toepler's formula, in that the ionized state of the gas is established only gradually, and may be considered a function of the quantity of electricity which has passed through the arc, the conductance increasing with this quantity.

On the other hand, Toepler's formula has some serious defects; namely,

1. The resistance, according to formula (**a**), being infinite at the instant of striking, no finite voltage should be able to start an arc;
2. Should the arc continue over an indefinite period of time, its resistance, according to Toepler, should drop to zero;
3. The ratio of the voltage to the current is assumed to be proportional to the length of the arc; in reality there is a considerable and concentrated fall of potential at the cathode, and some drop at the anode.

It is proposed, therefore, to generalize Toepler's formula as follows:

$$R_t = (k\,F + k^1)/(A_t + q) + r \qquad \textbf{(b)}$$

In this expression, k^1, q, and r are additional constants, introduced for the purpose of correcting the above-mentioned defects of the original formula. When $Q_t = 0$, *i. e.*, at the beginning of the discharge, R_t is no more infinitely large, but has a high finite value, $R_0 = (k\,F + k^1)/q + r$. With a steady arc, when $Q_t = \infty$, the resistance is no more equal to zero, but has the limiting low value of $R_\infty = r$. Furthermore, the resistance is assumed to increase more slowly than the length F of the arc, there being a correction term k^1.

Dr. Otto Mayr has given a general theory of condenser discharge through a resistance and a sphere-gap, using Toepler's formula for the resistance of a transient arc[2]. He has also determined some values of k from the available experimental data. The next step should be to extend his theory on the basis of generalized formula (**b**), and to determine the numerical values of the constants which it contains.

1. *Archiv fur Elek.*, 1925, Vol. 14, p. 306.

E. C. Starr: I should like to ask Dr. Compton and the gentlemen who have discussed his paper if they have any data on the order of magnitude of the transient resistance of an arc. I have reference to the type of arc that is initiated by a potential of several thousand volts between electrodes in air at normal pressure and temperature.

The size and shape of the electrodes, as well as the spacing, no doubt affect the resistance considerably. For example, the ionized path between the points of a needle-gap is not uniform in intensity of ionization and the effective cross-sectional area of the path is relatively small compared to the area of the path between large spheres or parallel disks. Hence it is to be expected that the resistance of an arc between the latter type of electrodes should have a lower value throughout the entire period of the transient than in the case of a needle-gap of the same spacing.

Dr. Slepian spoke of measuring the voltage transient of an arc. Perhaps he also recorded the current transient and could therefore readily determine the resistance characteristic.

The transient resistance equation suggested by Prof. Karapetoff should be of considerable value in the calculation of transients in circuits containing spark-gaps if the values of the constants can be determined.

R. W. Sorensen (communicated after adjournment): I should like to supplement what has been said by telling some of the interesting things relating to arcs that Dr. Millikan and I have found, as we have endeavored to produce a non-arcing switch for use on electric circuits. At California Institute of Technology we have been interrupting high-voltage, high-power electric circuits by means of switches enclosed in a vacuum chamber. To date, we have been very successful in our attempts to do this, largely because the arc at the opening of the switch is very small, and apparently removes a negligible amount of material from the switch terminal when the arc is struck. We have some switches showing practically no burning or pitting of contacts after 4000 operations. Also, by means of relatively small contacts, currents of several thousand amperes at approximately 50,000 volts, have been successfully interrupted. In performing these interruptions, the switch terminals have not been unduly pitted and since there is no pitting of the metal, it is rather difficult to account for the energy dissipation at the switch during the time of opening.

Dr. Compton has defined an arc "as a discharge of electricity between electrodes in a gas or vapor, which has a negative or practically zero volt-ampere characteristic and a voltage drop at the cathodes of the order of the minimum ionizing or minimum exciting potential of the gas or vapor," all of which may be true but we have found from our many experiences that if gas or vapor is required to maintain an arc, the amount required is indeed very small. Perhaps if we could hypothecate a liquid or gas, which will not vaporize at arc temperature, it would still be possible, though it may appear improbable, to start an arc in such a liquid. I should like to ask Dr. Compton how it would affect his difinition to leave out the words "gas or vapor" and have his definition read "an arc is a discharge of electricity between electrodes, which has a negative or practically zero volt-ampere characteristic and a voltage drop at the cathode of the minimum ionizing or minimum exciting potential of the material stripped from an electrode at the temperature of the arc." In other words, is it essential that there be a surrounding medium of gas or vapor in order that an arc may be struck by the electrodes.

If, for the moment we assume a medium of gas or vapor not essential to the establishment of an arc, we must, of course, look

2. *Archiv fur Elek.*, 1926, Vol. 17, p. 53.

for some other means of explaining the process by which an arc between electrodes is sustained even for a very short period of time. This presents a difficulty, which, however, may not be insurmountable. Contrary to public opinion, the best known vacuum is not a perfect insulator, in the sense that no electric current can be made to pass across such a vacuum, because we now know that electrons can be shot across vacuous spaces. When an arc is struck by the two separating electrodes, there must be present a host of ions or ionized particles, as well as free electrons which serve as the carrier for the arc. Is it not possible to picture a condition under which these carriers may be provided entirely from the electrodes, and not by a surrounding gas?

K. T. Compton: The work to which Dr. Slepian calls attention is, I think, some of the most interesting in connection with the theory of the arc. I made a reference to it in the paper, but I should like to call attention to just one thing for fear of being misunderstood.

There were two theories of Langmuir that have been discussed. One theory has no reference to the origin of the electrons. It would apply independently whether the electrons have thermionic or any other origin. It is merely a space-charge theory.

As to the other theory, *i. e.*, that electrons may be pulled out of the cathode by high electric fields, I think that we have there a possibility of two types of electric arcs. Of course there are often two or even more types of arcs. The character may change from one to the other, but both are recognized as arcs. It seems to me we have brought out in this discussion opportunity at least for two of these.

Dr. Slepian mentioned the case of a copper arc in which the cathode was not melted, and obviously didn't get to the melting temperature. On the other hand, we certainly do have copper arcs in which the copper does melt.

In Table I we notice two tungsten arcs, one with a current density of 3200 amperes per sq. cm., and the other with 700. In the latter case the thermionic emission can be calculated from the temperature that the arc reached. The tungsten melted, and at least reached the melting point of tungsten. In that case (See Table II) the thermionic emission, calculated from the constants of tungsten, comes as near 700 amperes per sq. cm. as the purity of the tungsten would justify. On the other hand, 3200 is clearly too high to be accounted for by thermionic emission. In tungsten we have these two different types, one evidently of thermionic origin and the other of different origin,—perhaps with electrons pulled out (Langmuir) or perhaps arising from intense ionization in front of the cathode (Slepian).

Nottingham used a special type of arc, especially designed to reduce heat conduction so that cathode temperature could rise. He got a large cathode spot. In the case of carbon also we have pretty good evidence of the large proportion of the emission thermionically, and in the case of Pointilite lamps and Tungar rectifiers where we can use a pyrometer to determine the temperature of the various parts of the cathodes, one gets pretty good agreement with the theory of thermionic emission.

In Table I, in the cases where we have current densities running into thousands of amperes per sq. cm. I think, with Dr. Slepian, that thermionic emission is not adequate to account for currents of that order. Another agency must be operative in such cases.

There are two ways in which the temperature may affect the ionizing potential. In the first place, the gas to be ionized may be dissociated from its molecular state into an atomic state as a result of high temperature. That such action is possible has been shown in experimental cases where it is possible to produce this dissociation under conditions that can be controlled, namely, in hydrogen, iodine, etc. In those cases the effect is always to reduce the ionizing potential. This action of temperature is indirect.

As regards any direct effect of temperature on the ionizing potential of the gas, this effect will probably be rather small because translating degrees centigrade into volts, about 8000 deg. cent. correspond to only one volt. There are no laboratory experiments that reach a temperature as high as 8000 deg. So the average energy imparted to electrons as the result of high temperature or to the molecules by high temperature would in general be only a fraction of a volt.

I don't know whether or not there are other ways in which the ionizing potential of the gas might be affected than these. The only ones I know that have been directly investigated have been dissociation of molecular gases into their constituents, and the direct thermal ionization of alkaline vapors in electric furnaces, as done at the Mt. Wilson Observatory.

With regard to the question by Mr. Starr, I am sorry that I cannot give the desired information because I have made no study of transient arc phenomena.

Professor Sorensen's suggestion that the ionization of materials stripped from the electrodes at the temperature of the arc be substituted for that of a surrounding gas or vapor appears to me to be quite permissible as including the interesting discharges which he described as true arcs. In fact such material is included in the term "vapor" in the sense that I have used. The important thing, as I see it, is the presence of some ionizable material in the space between the electrodes.

The great success of this current interrupter seems to be due to the fact that, at such low gas or vapor pressures, the mobility of the ions is so great that they effectively disappear from the arc space during the time of low voltage between voltage reversals. In high-pressure arcs as in oil-immersed circuit breakers, on the other hand, the ion mobility is so small that ions remain in in sufficient concentration to re-strike the arc after the voltage reversal.

In answer to Prof. Karapetoff I wish to say that I never discuss the question of an electric arc with anyone who has had any real practical experience with an electric arc without feeling how limited is the experience which we have in the laboratory. As I said, we physicists work with arcs on a small scale, and the attention of physicists has been devoted to arcs under the simplest conditions in order to find out something about the things going on in the arc. Unfortunately those aren't the arcs met with in engineering practise, where simplicity and even understanding of the phenomena are not the prime considerations. It may be, I am afraid, another generation of physicists which will be able to answer some of the questions which are uppermost in the minds of engineers.

PROTECTIVE DEVICES[1]

(Hunt)

Detroit, Mich., June 22, 1927

Alfred Herz: I want to mention a few things about the klydonograph. This device makes use of photographic emulsion coated on a base of celluloid or glass. The essential thing is the sensitivity of this emulsion.

A photographic emulsion after development will appear as a collection of grains of practically metallic silver. The size of these grains seems to have a direct bearing on the sensitivity of the emulsion. In general as the sensitivity is increased, the grains also increase in size. These grains appear under the miscroscope as separate islands, or clusters of islands with clear spaces between. Films usually supplied for cameras are coated with an emulsion of a fair degree of sensitivity. I believe such films are usually used in the klydonograph. It is possible to obtain emulsions which have practically no grain, such emulsions being usually made with albumin and not gelatine. They are abnormally slow for ordinary photographic work; but they make sensitive surfaces of such a fine grain that they can be used for miscroscopic photographs.

The usual photographic emulsions, made with gelatine, are quite hygroscopic, and I really believe that some caution and

1. A. I. E. E. Journal, August 1927, p. 779.

research should be carried on as to the effect of atmospheric conditions upon the results obtained with the klydonograph. I feel quite confident that some of the results are influenced by changes in the atmosphere. Therefore, if you want results that are really comparable, it is important first of all to make use of the same brand and speed of film or plates for all the tests contemplated. Furthermore, the experiments or tests should be carried on under some specific and similar conditions of the atmosphere.

I believe the Lichtenberg figures are produced by minute electric discharges between the grains mentioned, which will account for the ray-like images we obtain under certain conditions as well as for some of the figures resembling tree-like growth.

J. Allen Johnson: I wish to call attention to the matter of lightning-arrester standardization. It appears that by the use of the klydonograph, (which you may call an approximately accurate instrument), and the Dufour oscillograph, (which is probably a very accurate instrument), the fog which has for so many years surrounded the lightning-arrester question is gradually being dissipated. The difficulties in the way of the standardization of lightning arresters and lightning-arrester tests appear to be passing away. However, the lightning arrester is a device for dealing with transient voltages, for its protective value bears a relation to the transient voltage, not to the cyclic voltage which we generate on our lines. It therefore seems necessary, in order to standardize lightning-arrester characteristics, that we first standardize a transient voltage. That idea may sound revolutionary as we have always been accustomed to thinking of transient voltages as very uncertain in their nature, but the use of the klydonograph is beginning to give us pretty good evidence as to the true nature of the surges which occur on transmission lines. We find, for instance, that they are usually unidirectional, or, if not, highly damped. We are beginning to have evidence as to the steepness of their wave fronts.

It seems, therefore, that the time is nearly ripe to standardize a lightning surge for comparative tests of lightning arresters. This report suggests a definition of a standard surge.

I wish to announce that the lightning arrester subcommittee would be very glad to have any ideas on this subject so that the committee may have the benefit of them in working out this standardization. The committee has prepared a tentative form of standards for lightning arresters based upon—that is, starting from the basis of the report of the working committee in 1926. I have about twenty-five copies of this tentative form and I should be glad to give copies to any one sufficiently interested.

PUNCTURE VOLTAGE AS A PRECISION MEASUREMENT[1]

(Bush and Moon)

Detroit, Mich., June 24, 1927

W. W. Shaver: Mr. Moon stated that his results indicated that the breakdown was not a pyroelectric effect. I should like to mention some experiments which we have been carrying out on Pyrex and porcelain insulators which seem to warrant a similar conclusion.

These consisted in developing partial punctures; that is, carrying a puncture test almost to the point of breakdown, and then breaking the circuit and examining the partial puncture in the material. We have some photographs showing what might be described as "petrified lightning" in the breakdown in the Pyrex insulators. The discharge very much resembled a lightning flash permanently impressed in the glass. In the porcelain insulators, of course, we could not observe this in the same way, but by staining the material, we have found means to show that breakdown occurs in a similar manner. When examined under the microscope, the appearance of these partial punctures indicated that the breakdown was not due to a pyroelectric effect, but more probably to some type of ionization in the material.

F. M. Clark: In Pittsfield, we have worked for several years trying to devise a theory for insulation failure. We may not have made any more progress than other electrical laboratories, but we have reached some definite conclusions with regard to dielectric behavior. One conclusion is that the electrical breakdown of air-impregnated insulation is certainly not a breakdown phenomenon which we can explain on the basis of the pyroelectric theory. That checks, I believe, with the conclusions drawn by the authors. Air-impregnated insulation appears to give a breakdown which is a function of the chemical behavior and dielectric strength of air.

On the fifth page of their paper, the authors discuss the effect of large and small electrodes. They apparently reach the conclusion that the difference accompanying the use of large and small electrodes is a weak-spot difference. From such familiarity as I have with the paper they are using, I do not see how they can reach any other conclusion.

If the authors desire to get further evidence of the presence of weak spots, my suggestion would be to take a head set and locate those areas with low-voltage direct current.

In our work, we have extended the investigation to cover a number of laminations of this same type of paper as well as thick material, such as pressboard. We still find that the small electrodes give higher values than the large ones. This and other related observations make it almost conclusive to us that there is some effect present other than that which we can attribute to weak spots mechanically formed during the manufacture of the paper.

I was interested in the results with polished brass electrodes. We found the same thing. However, we have been led to believe that in all probability the low breakdown which is obtained for such thin materials when tested with new electrodes is due to the fact that the machinist has not polished the electrode surface sufficiently. With low-voltage direct current, weak-spot tests invariably show a larger number per sq. ft. with a new set of electrodes than with an old set. With frequent use, this difference between the electrodes tends to disappear. We have about concluded that the difference is largely due to a surface condition of the electrode which is mechanical and not chemical in any way.

Herman Halperin: In the body of the paper, the authors carefully point out the fact that the paper is only one-half a mil thick and for this reason thermal factors are favorable to disruptive breakdown.

Thermal breakdown. The equation for thermal breakdown is

$$E^2/\rho = C \text{ (Appendix A)}$$

Now, this equation does not contain a term for t (= time) since it is tacitly assumed that voltage is raised at a slow rate, and the equation is the boundary or limiting value of the stable or steady-state condition. It takes a few hours to reach a steady condition. However, in Bush's tests, 100 to 120 readings were taken per hour. This is at the rate of two per minute, and assuming that half of the time is consumed in relay operation, feeding the tape, etc., the voltage must have risen at least 600 volts in 15 sec., or 40 volts per sec. This is far from a steady-state condition and it may well be that a more critical study of the thermal theory including the time and thermal storage coefficient of the paper would yield results consistent with the data.

At the end of Appendix B, they have this sentence: "With a more thorough knowledge of insulation, the future engineer may be able to avoid thermal breakdowns altogether."

That is, to my mind, a very nice hope, but I don't believe the authors have presented enough data to warrant that possibility.

Now, in Chicago, during the past few years, we have made over

1. A. I. E. E. Journal, October, 1927, p. 1007.

300 tests at various times and durations on impregnated paper insulation in underground cables. We have found that about 75 per cent of the failures occurred in the region of the cable where the sheath temperature was higher than the adjacent sheath temperature. During the time the voltage was on the cable, our testing men went along the cable and felt it with their hands, and whenever they discovered a point a little hotter than the normal cable temperature, they placed the thermometer on the sheath and in that way we got the data as to the location of the so-called hot spots.

Furthermore we have found that a larger percentage of the failures was at hot spots when we had the thicker insulations, and so with real thin insulation, there may be more dissipation of the heat longitudinally so that it does not perhaps manifest itself in these hot spots.

Variation of thickness. If the failure is "disruptive" and follows "weak-spot" theory then running 1, 2, 3, . . or n paper layers through together, the dielectric strength should increase faster than the thickness of the layers. I should expect the equations to be of the form

$$E = E_1 (n + C \log n)$$

where E is strength of n layers and E_1 is the strength of one layer (as already determined). In other words, the weak spots would not line up and two papers would be far stronger than two times one paper.

However, on the other hand, if the thermal law were large or predominant, the strength could not be greater than

$$E = N\ E_1$$

and probably would follow the law

$$E = \sqrt{N}\ E_1\, n^{(1-x)}$$

If the failure were a complex combination of thermal and disruptive effects, (as is very probable), then the dielectric strength of several layers could follow the law

$$E = \phi\ (n)\ E_1$$

where $\phi\ (n)$ could be greater or less than unity for n = small number (1, 2, or 3, etc.). This may explain why different investigators may have found

$$E = n\ E_1$$

$$E = (n)^{3/4}\ E_1$$

$$E = \sqrt{n}\ E_1, \text{etc,}$$

Now, Bush and Moon are in an excellent position to throw some light on this dispute by making identical tests with $n = 2$, $n = 3$, etc., up to the limit of the generator, 4000 volts (using wider strips, if necessary). Perhaps they could go as high as $n = 5$. Of course, they would have to be very careful about the pressure, since I am assuming thickness $t = n\ t_1$.

Variation of material. The tests described are on dry paper, unimpregnated. Without great complication, I believe it entirely feasible to surround the electrodes with an oil bath and have the paper run through this bath—(several zig-zag passes around several rolls under oil). The oil should be continuously renewed with degasified oil—the oil to flow in a closed cycle from the bath, into a vacuum chamber, pumped out and through a filter back into the bath. A surface float would prevent much gas from being absorbed at the surface during the short time the oil remains in the bath. Then the paper (being so thin), would quickly saturate with oil by capillary action, and small air bubbles trapped in the fibers would be quickly absorbed by the degasified oil. The test would then be a true test of oil-impregnated paper.

Again, several thicknesses n should be tried up to the limits of the apparatus. They should be spaced apart during impregnation and combined under the electrode only at the last minute.

Also it might be feasible and very valuable to adapt the apparatus to test oil films. All that is necessary is to have a continual flow of oil in the bath and a strip (or strips) of paper with perforated windows moved one at a time under the electrode. These "windows" would serve the double purpose of making the oil stagnant during test and positively sweeping it out clean for the next test.

Correlation. Then, having the breakdown strength of paper, oil, and impregnated paper separately, all with variations of thickness and temperature, the probability is high that much more will be known regarding the dielectric strength of "solid" oil-impregnated paper insulation. For the effects of ionization a separate analysis would be necessary but much simplified by exact knowledge of the "solid" insulation in series and parallel with the ionizing voids.

Wm. A. DelMar: Messrs. Bush and Moon have made an important contribution to the study of dielectrics in calling our attention to the importance of a large number of tests of dielectric strength, in order to obtain significant averages. Workers on dielectrics are indebted to them for developing an apparatus for putting this principle into effect.

The actual results obtained in their tests, however, are of doubtful value, due to the nature of the dielectric which they have chosen. In the first place, unimpregnated paper is merely air baffled by a tangle of fibers, and is not at all representative of a solid dielectric. Secondly, the use of samples as thin as ½ mil., especially in a material of this character, was bound to result in the way they have shown. It was not necessary to make tests in order to discover the relation shown in Fig. 11 of the paper. I therefore feel that they have contributed little or nothing towards settling the disputed explanation of the lowering of dielectric strength with increase of area.

The idea illustrated by their Fig. 7 may prove to be an important one for researchers on dielectrics if the slopes of the Curves *A* and *B* are really as different as shown. That such is the case is indicated by their analysis of the work of Mündel.

R. H. Marvin (communicated after adjournment): This paper is of great interest on account of the ingenious methods used and the accuracy and completeness of the data obtained. However, the dielectric used in these tests,—untreated paper,—raises some question as to their significance.

If a piece of paper is examined with a microscope, it is seen to consist of great numbers of interlaced fibers. Such a structure indicates air spaces between the fibers, which is in accordance with its well-known porosity. The question then arises whether a puncture test on such a material gives a true puncture of the paper substance, or merely a breaking down of the air in the interstices. This is best checked by a comparison with the breakdown value of an equal air-gap.

Some excellent data on the strength of small air-gaps are given in, "The Sparking Distance Between Plates for Small Distances," Robert F. Earhart. *Philosophical Magazine.* 6th Series. Vol. I. 1901. Pp. 147-159. From Fig. 4 of this article the following values for various gaps and pressures are obtained:

Gap		Direct-Current Breakdown Voltage		
		Pressure, centimeters of mercury		
Millimeters	Inches	40	76	152
0.01	0.00039	340	385	490
0.02	0.00079	400	460	700
0.03	0.00118	460	530	900

The temperature is given as room temperature, and will be taken as 20 deg. cent. Since we may assume that changes in density caused by either temperature or pressure have the same effect, these data permit determining the breakdown at different temperatures as well.

Fig. 8 of the paper under discussion gives the breakdown strength of untreated paper 0.0005 in. (0.0127 mm.) thick at temperatures of from 0 deg. to 140 deg. cent. The curve is a straight line giving a puncture voltage of 586 at deg. cent.,

and 464 at 140 deg. cent. From the data given by Earhart let us determine these values on the assumption that the paper acts merely as a spacer for an air-gap. If the relative air density is taken as 1 at 20 deg. cent., then it will be 1.073 at 0 deg. cent., and 0.710 at 140 deg. cent. Plotting the values in the table and taking the values for a 0.0005-in. gap gives the following:

Pressure, centimeters	Relative air density	Breakdown voltage
40	0.527	354
76	1.000	406
152	2.000	547

Plotting the breakdown voltage against relative air density, we obtain the breakdown voltage at 0 deg. cent. (relative air density 1.073) as 415 volts, and at 140 deg. cent. (relative air density 0.710) as 373 volts. Thus the value for air at 0 deg. cent is 70.8 per cent of the value for paper, and the value at 140 deg. cent is 80.4 per cent. Both values for air are therefore a little low, but by nearly the same percentage.

There is also the possibility that the path of the spark among the paper fibers is not straight, but winding. This would increase the breakdown voltage of the air path, and bring the calculated values for air more nearly in accordance with the observed values for paper.

While it must be admitted that the data presented are not sufficient to prove that the untreated paper acted simply as an air-gap, still the relation is sufficiently striking to appear to deserve further study.

P. H. Moon: I was much interested in the suggestions made by Mr. Halperin. There is, of course, an immense field for further work along these lines; and our work, so far, can hardly be considered as more than a preliminary.

I agree with Mr. Del Mar that the material used was not just paper but was "air-impregnated" paper. I do not see, however, that this invalidates our results. If the breakdown were purely a breakdown of air, then—making due allowance for variations in the machine—I should still expect the results to be much more uniform than they were. The reason we used air-impregnated rather than oil-impregnated or varnished paper was simply to keep the number of variables as small as possible. In any measurement of insulation, the number of variables is large at best. If oiled or varnished paper had been used, additional "unknowns," connected with the kind and condition of the impregnating substance, would have been introduced.

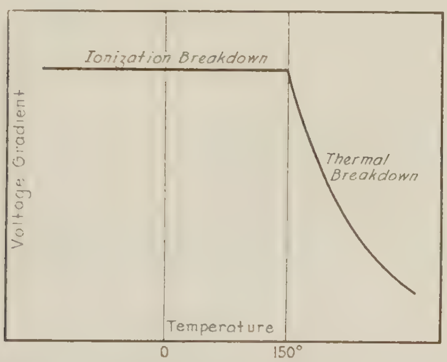


Fig. 1—Breakdown Gradient of Glass

Thickness = 1 mm.

From Joffe, Kurchatoff and Sinelnikoff, *Jour. of Math. and Physics*, April 1927

In the paper by Del Mar, Davidson, and Marvin,[2] the conflicting results obtained by different investigators have been pointed out. These discrepancies are undoubtedly due to the use of different materials by the various investigators. However, I think that the differences are partly due to the fact that some of these breakdowns occurred according to the thermal theories and some did not; that is, two investigators might test samples of the same material and might get entirely discordant results due to difference in thickness or temperature. One might get thermal breakdowns and the other might get ionization breakdowns.

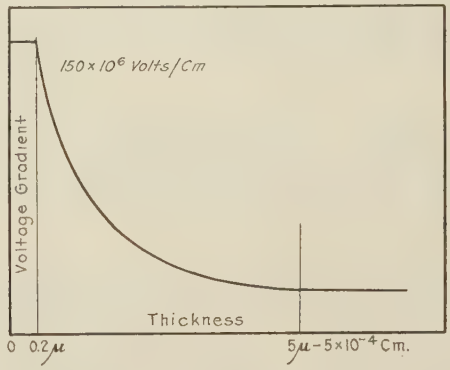


Fig. 2—Breakdown Gradient of Very Thin Specimens of Glass

That thickness and temperature have a vital effect on the mechanism of breakdown is shown by some recent work by a group of Russian physicists. I am referring to Joffé, Inge, Semenoff, Walther, and some others. These investigators have obtained a very good check on Rogowski's thermal theory with glass and with rock salt, provided the thicknesses were of the order of a millimeter or greater. In this case, if voltage gradient is plotted against temperature, the curve is very low near the melting point of the material and rises exponentially as the temperature is decreased (see Fig. 1 herewith). This is just as we would expect from Rogowski's theory. But the curve does not continue to go up indefinitely. At some temperature—150 deg. for glass—it makes a sudden break and becomes horizontal. Their tests have shown that it remains horizontal out to liquid-air temperatures.

Joffé has shown that the exponential part of the curve is due to thermal breakdowns, while the horizontal part is caused by ionization. In the latter part, he has shown that the breakdown gradient is

$$E = \frac{1}{u} \sqrt{\frac{2\,e\,P}{m}}$$

where u is the mobility of the ions, P is the ionization potential, and e and m are the charge and mass of the ion. This would indicate that the gradient at breakdown is independent of the thickness and temperature, provided the mobility stays constant.

It might seem that the horizontal part of the curve represented the maximum gradient obtainable, but some further work has shown that this is not the case. If gradient is plotted against thickness of the material (Fig. 2 herewith), for sheets less than 5 μ in thickness, the gradient goes up inversely as the thickness and rises to very high values. This again is supposed to be due to ionization by collision, but in this case the thickness is so small that there are insufficient ions to cause breakdown at the previous value (horizontal part of curve), and thus the gradient is higher than it would be for thicker materials.

Finally, a place is reached at about 0.2 μ, where the gradient is again a constant independent of thickness or temperature and having the immense value of 150 million volts per cm.

2. *Electric Strength of Solid and Liquid Dielectrics*, A. I. E. E. Summer Convention Detroit, Mich., June 24, 1927.

Breakdown here is probably due to actual rupture of the molecules of the substance.

So, to summarize, these investigators have shown that there are at least three distinct mechanisms of breakdown, and that these different mechanisms apply in different cases.

ELECTRIC STRENGTH OF SOLID AND LIQUID DIELECTRICS[1]

(Del Mar, Davidson and Marvin)

Detroit, Mich., June 24, 1927

F. M. Clark: I think if you read this paper carefully you will come to the conclusion that there is a considerable difference of opinion among "reliable experimenters." That is due no doubt, to a fact which heretofore has been greatly ignored. Not until recently have the chemist and physicist come into agreement with regard to the structure of the atom. The chemist has had his own chemical atom, and the physicist his own physical atom. The real reason has been that the physicist has entirely neglected the chemist's problems and the chemist has been guilty of neglecting the problems confronting the physicist.

The chemist is compelled to recognize two entirely different types of material; that is, the organic and the inorganic. The molecular structure involved appears to be different for each of these classes.

The electrical engineer, however, disregards both the chemist and the physicist; he works upon "insulation" and pays no attention as to whether it is organic or inorganic material. I think if you go through the paper and pick out the discrepancies, you will find one man talking about inorganic matter,—glass or the like,—and the other man talking about oiled paper or other organic material.

Another point I want to bring out in the paper is the difficulty in handling empirical equations. For example, take the case of the time–voltage curve, described on the third and fourth pages. Mr. Del Mar points out that the index of the time factor obtained by Peek and Montsinger is -4. Mr. Farmer indicates that it ought to be -7 instead of -4. Now, we have found that you can change that index as you please, by merely changing the materials with which you are impregnating the paper, or using the same impregnating material and changing the solid. In using an empirical formula, therefore, one must be very careful to apply it only to those limited cases for which it has been already proved.

Mr. Del Mar asserts that the dielectric strength-thickness relation for oil-impregnated paper is 0.72. It ought to be stated as 0.72 for mineral-oil-impregnated linen paper. If you go to Kraft paper, it is something else. As a matter of fact, we have been able to change the strength-thickness relation at will merely by changing the type of material with which we are dealing. We have gone from a value of 1 to an index point of about 0.58, either by changing the solid or the oil. That is brought out in a paper to which Mr. Del Mar refers as unpublished. It was published by Mr. Montsinger and myself in the *General Electric Review* in 1925.

There is one other point. It is mentioned that there are two classes of breakdown. I should like to add another. The mechanical effects leading to electrical breakdown have been entirely neglected, except at the bottom of the column. I think they are extremely important, especially to the cable engineer and operator.

I can cite a case. In 1923 at Pittsfield in some of our apparatus which had seen field service, we found considerable wax formation. The problem of the cause of this wax formation was turned over to our laboratory. The chemists attacked the work, and in a short space of time came to rather definite conclusions regarding its origin,—conclusions which have been quite widely accepted since that time. They claimed the wax was nothing but a polymerizing product produced by the action of corona on the oil. They concluded that the corona was first, the wax being the result and not the cause. Nevertheless, we continued the work to determine the possible advantage occurring from the use of an oil which would not wax easily under corona bombardment. We found that if we took oil which did not wax easily, or if we used air impregnated paper, and subjected either of them to corona, we got a mechanical shock and the paper disappeared. They told us it was the oxidizing action of ozone on the paper. However, we could not find carbon dioxide after or during the experiment. We repeated the experiment in a hydrogen atmosphere. If we stopped the experiments halfway, "needle points" were noted, such as Osborn described some time ago. Eventually, with a continued test, the paper lost its structure and disappeared as a powder.

Can an oil be produced which will not wax under corona bombardment? This problem may not yet have been solved to the satisfaction of all. Perhaps such an oil may be eventually found, although its existence does not appear probable at present. However, suppose such an oil can be prepared, what will be the result? We shall then have to consult the paper chemist in order to obtain a paper which will not disintegrate under corona. In the end, we may reach the surprising viewpoint that wax formation in cables is not our worst enemy after all. It at least gives us a true indication of the condition of the cable before failure. I believe wax formation in cables will be well worth the trouble it has caused if it serves to focus attention on the fact that, to insure proper service, the cable must be not only properly treated at the factory but throughout its entire existence before and after installation must be handled in such a way as to prevent the formation of voids, gas pockets and "dry" spots.

W. A. Del Mar: Mr. Clark's discussion clearly shows the necessity of attacking the insulation problem in a broad comprehensive way and of avoiding hasty generalizations. Since the preparation of our report, several papers on dielectric failure have appeared which, we are glad to note, support the main conclusions which we reached from the rather meager data previously available, such as the existence of two agencies of deterioration, neither of which is explained by the Wagner theory in its present forms, although a modified form of this theory may be expected to explain one of them.

W. F. Davidson: I think that we can only again emphasize the points which Mr. Clark has brought out; the need for clearly understanding that about which we are talking, and following the thing through with attention to every minute detail. So many times after the work is all done we find some essential point that might easily have been secured during the progress of the work still lacking. Somebody starts out to study the pyroelectric theory of material, and when he gets through, he finds that the thing has acted in a disruptive way, and that evidence bearing on the disruptive failure is quite useless because it has been collected in such a haphazard way.

INSTRUMENTS AND MEASUREMENTS[1]

(Knowlton)

Detroit, Mich., June 22, 1927

F. A. Brownell: I think it would be in order, at this time, to call the attention of the Instruments and Measurements Committee to the fact that we have no standard calibration curve for sphere-gaps at voltages over 500 kv.

There seem to be two schools of thought regarding high-voltage measurements. One is that sphere-gaps are used to calibrate voltmeters and the other is that voltmeters are used to calibrate sphere-gaps.

Due to the number of high-tension laboratories which we have in this country, it would seem as if some action should be taken on this subject.

1. A. I. E. E. Journal, October, 1927, p. 1002.

1. A. I. E. E. Journal, October, 1927, p. 1033.

J. T. Tykociner: The Report of the Committee on Instruments and Measurements gives a very valuable review of recent progress made in high-frequency measurements. Radio engineers may be interested also to know that a method has been developed to determine the constants of antennas by means of models. The application of the principle of similitude to radiating electrical systems leads to simple methods of predetermining the capacity, inductance, frequency and radiation resistance of any form of antenna. For this purpose a small model is made of the antenna with the surrounding buildings. For the excitation of a model m times smaller than the original antenna frequencies are used m times higher than would be necessary for the original antenna. Satisfactory results were obtained with a model coefficient $m = 100$, the models being excited by short-wave transmitters with a frequency 30 to 60 megacycles. For the design of elaborate antenna constructions it may be useful to predetermine the constants and to check the results of calculations by means of such models. The investigation was carried out at the Engineering Experiment Station, University of Illinois, Urbana and the result published in Bulletin No. 147. "Investigation of Antennae by Means of Models." The application of models for predicting directive characteristics of antennas is discussed in Bulletin No. 161 on "Short-Wave Transmitters and Methods of Tuning." A brief account of this work was given in *Science Abstracts*, Section B, Vol. 28, 1925, p. 468. An illustrated article of the method was published in *The Engineer*, London, Nov. 12, p. 518-519 and Nov. 19, 1926, p. 548-549.

THE ELECTRICAL RESISTIVITY OF INSULATING MATERIALS

DETROIT, MICH., JUNE 24, 1927

(CURTIS)

F. M. Clark: With regard to Dr. Curtis' paper, I do want to emphasize the type of conduction which he calls colloidal conduction. I think that this is a type which we will have to recognize and consider in more detail than we have. When you consider that almost all of our insulations are colloidal in nature if not true colloids, you can see the significance of that type of conduction. I recognize that colloidal conduction is similar in many respects to electrolytic conduction. However, it owes its origin to larger charged masses and may occur in mediums where electrolytic conduction would be least expected.

Dr. Curtis discusses the conduction over the surface of solid insulators. The effect of water-vapor condensation is cited and its importance discussed. Although the author illustrates the effect on inorganic materials such as quartz and porcelain, it should not be overlooked that conductivity in fibrous materials appears to be closely related to the cases given. Our researches at Pittsfield have not been entirely completed, but we have already obtained considerable evidence that the quantity of water contained in an oil-treated paper, while important, is not the sole factor determining the a-c. and d-c. conductivity. It appears that the effect produced depends very largely on whether the water vapor present is absorbed on the surface of the paper fibers or whether it be held within the fiber wall.

USE OF HIGH-FREQUENCY CURRENTS FOR CONTROL[1]

(C. A. BODDIE)

DETROIT, MICH., JUNE 23, 1927

Chester Lichtenberg: One thing that is disturbing to the designers, as well as the operators, is the high cost of the equipment required for carrier-current supervisory control. At present the cost of wires is large, however, the terminal apparatus required for radio supervisory equipment is also large. It is therefore necessary to make a quite careful analysis of the situation before a reasonable conclusion can be drawn as to whether or not it is cheaper to use supervisory equipment employing wires or supervisory equipment using carrier current. From some studies which we have made, the wires seem more economical for distances up to about 25 mi., beyond that distance however, the carrier-current design becomes feasible.

The ambition of radio engineers seems to be to put supervisory equipment on high-tension transmission system. This is a splendid idea. It should be recollected however, that the supervisory equipment is most essential during times of stress, and such times will most always coincide with high-tension transmission-circuit interruptions. Following this idea further, it is gratifying to note that the Alabama Power Company instead of using its high-tension transmission system, uses insulated ground wires. This follows in general the practise of the Chicago, South Shore and South Bend Railway Company which uses a single wire for the control and indication of eight automatic substations.

L. H. Junken (communicated after adjournment): A system of street-light control using high frequencies superimposed upon the distribution feeders has been developed by the General Electric Company in its general development of high-frequency control. This system uses a vacuum-tube oscillator for the generation of high-frequency power. This oscillator has an output of approximately 100 watts and is coupled to the distribution feeders on the line side of voltage regulators at the substation. The oscillator is built in the form of a switchboard panel and is approximately 33 in. wide, 76 in. high and 15 in. deep. The coupling capacitors used are small due to the small amount of control energy required and to the high frequency used which is about 40 kilocycles. The coupling capacitors are permanently installed on each feeder over which control is to be sent. The oscillator can then be switched from feeder to feeder on the low side of the coupling capacitors by means of low-voltage switching equipment. Since the frequency is high, the possibility of telephone interference is avoided and the presence of voltage regulators between the oscillator and the station bus prevents any appreciable amount of energy from flowing toward the bus and insures a maximum amount of energy flowing toward the feeder. This is a very economical arrangement, because it uses very small amounts of control energy.

The receivers are located along the feeders where pole-type constant-current transformers are to be controlled. The receivers are coupled to the feeder through small coupling capacitors which can be mounted on the crossarm in a way similar to that used for mounting lightning arresters. The receivers use a single vacuum tube for the detection of the high-frequency control current. This tube is operated at reduced rating and has a life of approximately one year. All of the power for the filament, grid and plate potentials of the vacuum tube is taken from the secondary lines, no batteries or rectifier being required. The whole receiver is enclosed in a weather-proof sheet-steel box arranged for mounting on a pole. The receiving tube operates a d-c. relay in its plate circuit and this relay in turn operates a time-selector relay which controls the position of the switch in the primary of the constant-current transformer. The time-selector relay is so arranged that it closes the lighting circuit on a short impulse of control energy and opens the circuit on a longer impulse of control energy. The receivers are built to receive a suitable band of frequencies and require no tuning or other adjustments after their installation.

This system of control has been installed in service for street lighting in Schenectady and Rochester, N. Y., also Bayonne, N. J., for about two years and has given very satisfactory performance.

A. H. Kehoe (communicated after adjournment): While the author mentions the control of multiple street lighting by high-frequency relays, the section of the paper covering applica-

1. A. I. E. E. JOURNAL, August 1927, p. 763.

tions of street-lighting control deals primarily with series lighting circuits. This is probably due to the fact that the multiple type of street lamp has not been extensively used in the past except in a few large cities. As there are economical advantages to be gained by using this type, provided a satisfactory method of control exists, it should be emphasized that the principal disadvantage of the multiple type of lighting in the past has been the difficulty of control. In the future, comparisons of the series vs. multiple systems for street-lighting applications should take this development into consideration, as it extends the field where multiple street lighting will prove to be the more economical of the two types of system.

H. M. Trueblood (communicated after adjournment): Mr. Boddie's paper and other recent ones along similar lines serve to call our attention to the extent of the range of application of the carrier-frequency art. It was only about ten years ago when carrier-frequency telephone and telegraph circuits first appeared in the Bell System. Since then we have seen, first, a rapid development of carrier frequencies in commercial telephone and telegraph circuits; second, the use of carrier frequencies superposed on power transmission lines for the private communication services of power companies, and we now have the announcement of working applications of carrier frequencies for control purposes, a field which Mr. Boddie expects will be extensively widened.

In making note of these achievements we do so with the satisfaction any electrical engineer must feel in the furthering of the applications of electricity to the useful arts. We ought, however, to realize that the development and application of carrier frequencies along these three lines and others which may later appear, need to be carried out with proper regard to the possibilities of interference. In the development of commercial carrier-frequency telephone and telegraph circuits, where different systems are carried on the same pole line, engineers of the Bell Telephone System have been made fully aware of the difficulties of the interference problem, which appears here as a cross-induction problem more formidable than at voice frequencies. Methods which have been used to deal with it have included special attention to circuit balance, the suppression of the carrier wave itself, the use of a single side band, the selection of appropriate power levels, and a system of frequency allocations within the frequency range employed. No other methods than these appear to be open to us for dealing with the problem of induction in commercial communication circuits from carrier-frequency circuits as applied for control or communication purposes in connection with power lines, and the most fundamental of these methods at present is undoubtedly frequency separation. In fact, unless carrier-frequency circuits for communication or control purposes in connection with power-circuit operation can be made to approach commercial communication circuits as regards balance and energy levels, I know of no means of avoiding interference in situations of close exposure other than frequency separation.

There is no serious situation at present as regards interference in commercial carrier-frequency communication channels from power lines, or any of the carrier-frequency applications used in connection with power-system operation, so far as I know. I believe that those of us who are working in carrier-frequency development in its various aspects should see that this fortunate condition continues. It is of interest in this connection to refer to the work of one of the project committees organized under the Joint Development and Research Subcommittee of the N. E. L. A. and Bell Telephone System which has been charged with, and is actively pursuing, a study of the problem of interference in carrier-frequency channels.

C. A. Boddie: I fully agree with Mr. Lichtenberg when he states that the application of high-frequency currents for control purposes is at present limited considerably by the high cost of the equipment. It is only on relatively long distances that there is a sufficient saving to justify the use of high-frequency currents so far as first cost is concerned. A good deal of work is being done in an effort to reduce these costs and it is hoped that a considerable improvement can be effected. But it is not the matter of first cost alone which is the chief consideration and stimulus to the use of high-frequency currents. It is rather the need of a mechanically more sturdy and more stable circuit than is attainable with telephone-line construction. It is this mechanical strength which can withstand sleet and storm and flood conditions inherent in power-line construction that offers the chief inducement to the use of high frequencies on such a line for communication and control.

The type of control described by Mr. Junken using relatively high frequencies generated by vacuum tubes is referred to in the paper. This type as stated is not suited to the control of multiple street lights, because such high frequencies will not pass through transformers and because of the size and cost of the individual receiving devices, each of which requires a vacuum tube and accessories. The system has a legitimate field of application for the remote control of regulating transformers for series lighting, since for this application relatively few receiving devices are required and the size and cost per unit is not a serious objection. The control currents are not required to pass through transformers as in the case of multiple lighting, but are taken off the high-voltage feeder by means of special coupling condensers.

I am glad Mr. Kehoe has emphasized the fact that the development of the system of control by the use of medium frequencies puts a new complexion on the problem of multiple vs. series street lighting. As he says the principal obstacle to the use of the multiple system has been the difficulty of control. In large cities the multiple system of distribution reaches everywhere. To supply street lights by the series system means a system within a system; that is, "duplication." The economic advantages of the multiple system which is universal for everything except street lighting may now be secured. The medium-frequency system of control was developed with special reference to the problem of controlling multiple street lights. Although as brought out in the paper it can be applied to the control of series lighting, its principal field of application is to multiple lighting. Perhaps this was not brought out in the paper as clearly as it should be.

With reference to Mr. Trueblood's discussion on the subject of interference, I might state that so far as street-light control is concerned he will have little to fear. The development has not overlooked the question of interference with existing telephone lines. In the first place, the system is worked out so that the control frequency is applied to the line only twice a day and this is only for a period of several seconds. One of these operating periods comes at a time when interference if there should be any, would be of little consequence. In the second place, the control currents are confined entirely to the metallic conductors of the power system and are not permitted to return by way of ground. In the several installations which have been made there is no known interference with the telephone system, even that in the substation itself being immune.

A NON-ROTARY REGENERATIVE TELEGRAPH REPEATER

(Connery)

Detroit, Mich., June 23, 1927

W. C. Peterman: I should like to point out that a type of rotary repeater differing from those shown in Figs. 1, 2 and 3 in Mr. Connery's paper is shown in Fig. 2 of the paper by Herbert Angel[1].

In the type of rotary shown by Mr. Angel, which has been

'*Printing Telegraphs on Non-Loaded Ocean Cables,* A. I. E. E. Summer Convention, Detroit, Mich., June 23, 1927.

1. A. I. E. E. Journal, Sept. 1927, p. 933.

used very successfully by the Western Union on their long ocean cable circuits, the pick-up circuit is separate from the locking and sending-on relay circuit although they are both connected to segments on the same segmented rings. This regenerator gives complete regeneration; that is to say, if an impulse is received of sufficient duration to be locked up, the regenerated signal is of a definite duration.

In this respect it is the equivalent of the rotary repeater shown in Mr. Connery's Fig. 3, although it uses but one segmented ring and two unbiased relays when regenerating two-current signals, which tends for simplification. The repeater as shown in Fig. 2, however, is wired for cable Morse three-current signals and, therefore, uses four biased relays.

Herbert Angel: Considerable work has been done by the Western Union Telegraph Company with regenerative repeaters of both the rotary and non-rotary types, the latter being known as the fork regenerative repeater. Opinions differ as to which is the more advantageous type to use; each probably has its special field.

In a great many cases it has been found more desirable to use the rotary type with segmented rings for leaking off printers. Aside from this there is the question of brush transmission in one case and relay contact transmission in the other. It is the more general opinion that brush transmission is superior to relay contact transmission. For higher speeds the rotary type should be more reliable than the fork type as now developed.

A. F. Connery: Answering Mr. Peterman's comments, the diagrams of the rotary repeaters shown were of course made as simple as possible, and on some of them it would be necessary to add accessories to make practical repeaters such for example, as locking up the polarized transmitting relays to make them less subject to vibration and things like that.

We do not make claim for the non-rotary repeater that it will send out a better signal than a rotary repeater, but the advantage is that it is simpler, and easier to maintain and we think that in the hands of the average attendants, the net results will be better.

There are some purposes for which the rotary repeater is better; for instance, where we want drop-channel and others circuits like them. When we want to get into complicated circuits it is better simply to add segmented rings on the rotary mechanism, but on a straightforward regenerative repeater I think there are some advantages for the non-rotary repeater.

Mr. Angel's comments upon the advantages of brush transmission over relay transmission are well founded. In fact until recently there was a very decided advantage of brush transmission over relay, but relays have recently been developed with very low transit time; that is, the relays travel from one contact to the other at very high speed and means of reducing chatter have been developed so that now I think brush transmission has very little if any advantage over relay transmission and of course there is less maintenance of the relay contacts.

PRINTING TELEGRAPHS ON NON-LOADED OCEAN CABLE

(Angel)

Detroit, Mich., June 23, 1927

A. F. Connery: The method of cable signaling, suggested by Gulstad in 1898 and which is used in the operation of the printing telegraph system described by Mr. Angel, appears to be the only method available if the 5-unit 2-element code is to attempt to compete with the widely used 3-element unequal letter cable code on long cables. The application of this signaling method to the old-style duplex cables which span the Atlantic is no mean achievement, and many difficult and trying problems, of which little mention is made in the paper, must have been solved.

I note Mr. Angel states that the speed of a certain cable was increased from 300 to 375 letters per minute. I wonder whether net increase is meant. My impression has been that the signaling described in this paper, whereby the single-element impulses are attenuated in the cable and are generated locally in the receiver, requires a high grade of duplex balance which is difficult to secure and maintain. It would seem that the time lost in adjusting and regulating would be greater than for the older methods of transmission.

A large proportion of the cable traffic at the present time is in code, and each word usually has the same number of letters. In a number of codes, each group consists of ten letters. One advantage of the well-known 3-element cable code is the ease in which errors may be detected by the transcribing operator. A loss or gain of an impulse due to a change in balance, lightning kick, improper adjustment of apparatus, etc., at some relay station, will either make an unintelligible signal combination or will cause a 10-letter word, for example, to become a 9- or 11-letter word. In any case, the error is usually apparent to the transcribing operator who can have the doubtful part of the message repeated.

The 5-unit code does not possess this advantage, and the loss or gain of a pulse will cause a wrong letter to be printed in place of the proper letter. Each word will have the proper number of letters and the receiving operator will be unable to detect any irregularity.

For plain English traffic the printer on slow-speed cables is attractive, but for code traffic it appears to be at a disadvantage as compared to the widely used cable code.

The foregoing remarks do not apply to the new high-speed inductively loaded cables which must be multiplexed to secure satisfactory traffic distribution and have no duplex balances with which to contend.

W. A. Houghtaling: Mr. Angel's paper describes printer operation on ocean cables in its simple form, that is, single-channel operation or one printer and transmitter at each terminal of the cable. It may not be clearly understood, however, that the printer operation is not limited to a single-channel, as by the use of a rotary distributor, several channels are possible. In fact, two other cables are being operated with four and five channels respectively, and still another is operating with two channels.

The cable which is operating as a two-channel circuit is of the same type as that referred to in the paper, while the two which provide four and five channels are the loaded type.

One of the points brought out in Mr. Angel's paper that seems to me to be quite interesting is the way he has shown the various steps of increased output of a type of cable laid fifty years ago, obtained by the use of improved terminal apparatus and improved operating methods. It would seem that the cable engineers and cable manufacturers of half a century ago built better than they realized. This type of cable has been able to meet the ever increasing traffic requirements through all these years by means of the terminal improvements mentioned until it is now carrying more than five times the amount of traffic it could handle originally.

W. C. Peterman: The securing of the maximum message-carrying capacity of a cable which is the primary object of the cable engineer depends both on sending as many cycles per second of signaling current as possible over the cable and getting the greatest amount of intelligence out of every cycle of current. It was pointed out in the paper that as the transmitting frequency is increased, the attenuation of the signals becomes greater, and at the receiving end of the cable more and more amplification of the signals must be used in order to get current strong enough to operate the mechanical relays. Of course with vacuum-tube amplifiers the amount of amplification possible has been increased vastly over what was previously obtainable, but unfortunately it has been found that all of the amplification thus possible cannot be used in practise because of the presence of electrical disturbances. These dis-

turbances may be either man-made, such as interference from nearby power lines or other cable circuits, or from the duplex balance of the cable itself; or they may be electrical disturbances from apparently natural sources of unknown origin.

The difficulty of receiving weak signals from distant radio broadcasting stations when any considerable amount of static is present, no matter how much amplification is available, is familiar to everyone. In fact, greater amplification does not help at all after a certain point is reached; it only adds to the confusion. We have just about the same problem with receiving weak signals over a long cable. It thus becomes necessary to secure the greatest possible amount of information, as it were, from each received impulse, since we cannot increase without limit the number of impulses transmitted per second.

I just wish to emphasize, therefore, in the system described by Mr. Angel, and shown in his Fig. 1, that only the impulses of one-half the fundamental frequency must be received with sufficient strength to be well above the interference level, although we are getting the full amount of information out of the impulses transmitted at the fundamental frequency which impulses, by their very absence, because of greater attenuation, are caused to be filled in automatically at the receiving end. Thus we get the benefit of having to receive through the interference only, the comparatively stronger signals of one-half the working frequency while getting the full message-carrying advantage of the highest frequency impulses.

Herbert Angel: I should like to say, in reply to the comments by Mr. Connery, that the excellent method for increasing the speed of cables suggested by Mr. Gulstad in 1898, while quite successful for operating comparatively short lengths of cable, had never been found practicable to apply to long cables. This was pointed out by Messrs. Judd and Davies, of England, in their British patent of 1913, in which, for the first time, a method was described for filling in attenuated impulses for a synchronous system on long cables. The Western Union printing system does not use the Gulstad vibrating method for filling in the impulses.

Replying to Mr. Connery's query about the increased speed with printer operation, the output of 375 letters mentioned in the paper is a net output.

In reply to Mr. Connery's comment about the high-grade balance required for cable-printer operation, I should like to point out that in getting the 375-letter output which is an increase over the output obtained with cable Morse code, the frequency of the double received impulses is even then less than the maximum fundamental frequency when using cable Morse code. Therefore the received signaling impulses are larger and are better able to stand any slightly greater balance disturbance. Further, it has been found by repeated check, that under these conditions the cable printer is as accurate as the cable Morse code.

ELECTROMAGNETIC WAVES GUIDED BY PARALLEL WIRES[1]

(LEVIN)

DETROIT, MICHIGAN, JUNE 23, 1927

L. C. Peterson (communicated after adjournment): In connection with some tests planned to determine the inductive coupling at the higher frequencies between different wires of a system of parallel wires, a theoretical study was made in June and July of 1926, based on a paper by Professor Pleijel entitled "Current and Voltage Relations in a System of Parallel Conductors" and given as reference No. 18 in Mr. Levin's paper. In his paper, Professor Pleijel gives a set of linear equations connecting the terminal currents and voltages of a multi-wire line. In the underlying transmission theory, the ground is assumed to have infinite conductivity. Mr. Levin states that he has demonstrated the validity of Pleijel's equations, as regards their form, when the finite conductivity of the ground is taken into account. Such a demonstration is quite unnecessary; indeed, the fact that the equations maintain the same form irrespective of any assumption regarding the ground conductivity, or any approximation introduced in the transmission theory, follows immediately from the general properties of an n-terminal network. The coefficients in Pleijel's equations (given as eq. (**20**) in Levin's paper) uniquely specify the system and hold for all possible terminal connections of the line wires. They offer, therefore, a means of determining the induction in systems of parallel conductors. In a limited number of cases, these coefficients may be calculated from the dimensions of the system. However, calculations being rather laborious, it is advantageous to resort to the experimental determinations of the coefficients.

In a system of n conductors, $n\ (2\,n + 1)$ independent coefficients will be necessary to define the system completely, but if the system is electrically symmetrical around its midpoint, this number of independent coefficients is reduced to $n\ (n + 1)$. For instance, an unsymmetrical three-phase system is determined by $3\ (6 + 1) = 21$ coefficients and a symmetrical three-phase system by $3\ (3 + 1) = 12$ coefficients. It is obvious that in the general case the determination of $n\ (2\,n + 1)$ coefficients will be required and hence, $n\ (2\,n + 1)$ measurements.

Methods for experimental determination of the coefficients b in eq. (**20**) of Mr. Levin's paper have been worked out. It can readily be shown that all the coefficients are obtainable from open- and short-circuit impedance measurements on the individual wires or on combinations of these wires.

S. A. Levin: The validity of Pleijel's equations for any finite value of earth conductivity, eq. (**20**), can be shown as done in the paper of reference (18) provided eqs. (**13**) and (**15**) are demonstrated for finite conductivity. According to Mr. Peterson, the validity of Pleijel's equations for any finite value of earth conductivity follows from the theory of an n-terminal network. It seems to me that the application of this theory to a system of parallel conductors also requires that eqs. (**13**) and (**15**) are demonstrated for finite conductivity. This is the only demonstration attempted in my paper. I cannot see, therefore, that it contains any unnecessary demonstration whether Pleijel's equations are obtained one way or the other.

EXTRACTING OIL FROM COAL

A German concern has recently stated that it has entered into an agreement with an American company covering patents relating to the processing of oil from coal. At the same time, the Minerals Division of the Department of Commerce made public a report from its Trade Commissioner at Berlin to the effect that imports of petroleum products into Germany are being received at a record rate.

One of the chief objectives in the development of oil-from-coal-processes in Germany is to obtain freedom from dependence on foreign sources for German petroleum, which is imported mostly from the United States.

Our Trade Commissioner pointed out that the volume of imports this year probably will exceed 1,500,000 tons, and that the present rate is 300,000 tons annually more than last year. It is estimated, he states, that only 100,000 tons of synthetic petroleum will be produced by the hydrogenation of lignite in 1928, so that apparently the synthetic production will not take care of the natural increase in demand.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

132-Kv. Cables and Other Timely Subjects for Chicago Meeting, November 28-30

A wide range of very timely subjects is on the technical program for the Regional Meeting which will be held in Chicago, November 28, 29 and 30.

A symposium on 132-kv. cables recently installed in Chicago and New York will be one of the major features of the program.

There will be papers also on the operation of interconnected systems and equipment employed on them such as alternators, frequency changers and relays. The proper division of load among power plants is the subject of a related paper. Another group will deal with railroads covering the Illinois Central electrification, mercury arc rectifier experience and storage-battery locomotives. Other excellent papers will treat of high-speed recorders of electrical conditions, vacuum-tube voltmeters and rectifiers, telephone toll plants and reclamation of waste material in manufacturing plants.

A noteworthy part of the meeting will be the Student Convention held on November 28, at which Students will discuss the problems of the District Branches as well as conduct a technical session consisting of Student papers.

A number of interesting inspection trips will be made to the numerous central-station and industrial properties which abound in Chicago and nearby.

In addition to the technical features a banquet will be held on the evening of Tuesday, November 29.

The Regional Meeting Committee which is directing the plans is as follows: B. G. Jamieson, Chairman; A. G. Dewars, Secretary; K. A. Auty, Treasurer; F. H. Riddle, J. T. Rood, W. O. Kurtz and H. E. Wulfing.

The local committees and their officers are as follows: *General Committee*, B. G. Jamieson, Chairman; H. E. Wulfing, Vice-Chairman; W. O. Kurtz; *Papers & Meetings Committee*, P. B. Juhnke, Chairman; *Hotel & Registration*, Jack Kearns, Chairman; *Banquet & Entertainment*, C. W. Pendell, Chairman; *Transportation & Inspection Trips*, G. M. Gumm, Chairman; *Printing & Publicity*, F. R. Innes, Chairman; *Student Convention*, J. F. H. Douglas, Chairman; C. M. Jansky, Vice-Chairman; *Finances*, K. A. Auty, Chairman.

The tentative program of the sessions is as follows though possibly there will be changes before the final program is decided upon.

TENTATIVE PROGRAM OF CHICAGO REGIONAL MEETING

NOVEMBER 28-30, 1927

MONDAY, NOVEMBER 28

Devoted to Branch Conferences and Student Technical Sessions.

TUESDAY, NOVEMBER 29, 9:15 A. M.

Symposium on 132-Kv. Single-Conductor Lead-Covered Cable.

a. *Introduction, Economics and Commercial Demand*, P. Torchio, The New York Edison Company.

b. *Theory, Design and Development*, L. Emanueli, Societe Italiana Pirelli.

c. *Manufacture, Inspection and Testing*, W. S. Clark, General Electric Company.

d. *Installation*, A. H. Kehoe, United Electric Light and Power Company; C. H. Shaw and J. B. Noe, The New York Edison Company, and D. W. Roper, Commonwealth Edison Company.

NOVEMBER 29, 2:00 P. M.

Illinois Central Electric Operating Experience, W. M. Vandersluis, Illinois Central R. R.

Operating Experience with 125-Ton Storage-Battery Locomotive in Chicago Railroad Terminals, Edward Taylor, General Electric Company.

Operating Performance of Rectifiers, Caesar Antoniono, Chicago, North Shore and Milwaukee R. R.

Synchronous Motors for Steel-Mill Operation, W. T. Berkshire, General Electric Company.

WEDNESDAY, NOVEMBER 30, 9:15 A. M.

The Chicago Regional Power System, E. C. Williams, Public Service Company of Northern Illinois.

The Hall High-Speed Recorder, E. M. Tingley, Commonwealth Edison Company.

Relay Protection for Interconnected Systems, L. N. Crichton and H. E. Graves, Westinghouse Electric and Manufacturing Company.

Alternator Characteristics Under Conditions Approaching Instability, J. F. H. Douglas and Edward W. Kane, Marquette University.

NOVEMBER 30, 2:00 P. M.

Reclamation of Waste Materials in the Western Electric Factories, C. D. Hart, Western Electric Company.

Telephone Toll Plant in the Chicago Region, Burke Smith and G. B. West, Illinois Bell Telephone Company.

The Vacuum-Tube Rectifier, J. H. Kuhlman and J. P. Barton, University of Minnesota.

A Two-Range Vacuum-Tube Voltmeter, C. M. Jansky, Jr., and C. B. Feldman, University of Minnesota.

Pacific Coast Convention, Del Monte, California, September 13-16, 1927

From a professional standpoint, the Sixteenth Annual Pacific Coast Convention of the Institute held at Del Monte, California, September 13-16, was highly successful. The social features also were very enjoyable to the 254 members and guests present.

The technical program contained many high-grade papers on important subjects, and their discussion was interesting and valuable. Excellent balance was maintained between the technical sessions and other scheduled events.

Student Activities

In accordance with plans made previously by Professor R. W. Sorensen, Chairman of the Committee on Student Activities, Pacific District, and the Convention Committee, the opening event of the Convention was a luncheon meeting of Student Branch Counselors and Chairmen of the District, held on Tuesday, September 13th, at 12:30 p. m. Each of the seven Branches in the District was represented by its Counselor or other faculty members and all Chairmen were present.

Following the luncheon, a Student Branch Conference and a Student Technical Session were held. During the latter, 18 student papers were presented briefly and discussed. (A more complete account of these meetings will be found in the Student Activities department of this issue of the Journal).

Opening Technical Session

The first technical session was called to order promptly at 9:30 a. m. Wednesday, September 14th by Mr. P. M. Downing, Chairman of the Convention Committee and retiring Vice-President of the Pacific District. After welcoming the members and guests to Del Monte, Mr. Downing called upon Mr. D. I. Cone, Vice-Chairman of the Convention Committee, and Mr. E. A. Crellin, Chairman of the Entertainment Committee, to make announcements regarding the various features of the Convention. He then introduced President Gherardi who presided over the remainder of the session.

In his opening remarks, President Gherardi mentioned briefly certain features of the organization of the Institute, and commented particularly upon the present provisions for Districts, Sections, and Branches to bring Institute activities within a reasonable distance of every member in the United States and Canada. He said the present organization of the Institute appears to be meeting the needs of the country, but that the management will always be responsive to any need of changes to meet new conditions.

The following technical program was then presented:

Advance Planning of the Telephone Toll Plant in Long-distance Communication, by J. N. Chamberlin, The Pacific Telephone and Telegraph Company. (Presented by the author.)

Tandem System of Handling Toll Calls in and About Los Angeles, by E. Jacobson and F. O. Wheelock, American Telephone and Telegraph Company and Southern California Telephone Company, respectively. (Presented by F. O. Wheelock.)

Discussion of the above two papers was presented by Messrs. M. R. Sullivan, R. C. Barton, J. P. Jollyman, B. Gherardi, and N. B. Hinson.

Coupling Capacitors for Carrier-Current Communication over Power Lines, by T. A. E. Belt, General Electric Company. (Presented by Dr. L. F. Fuller.)

Carrier-Current Relay Protection, by A. S. Fitzgerald, General Electric Company. (Presented by the author.)

The above two papers were discussed by Messrs. E. R. Stauffacher and L. F. Fuller, and written discussions by Messrs. Roy Wilkins and William Dubilier were received.

Wednesday Afternoon Technical Session

Mr. P. M. Downing called the Wednesday afternoon session to order and introduced Mr. L. W. W. Morrow, Managing Editor of the *Electrical World*, who presided. The following papers were presented:

Relation Between Frequency and Spark-Over Voltage in a Sphere-Gap Voltmeter, by L. E. Reukema, University of California. (Presented by the author.) Discussion by Messrs. H. J. Ryan, R. J. C. Wood, F. O. McMillan, D. I. Cone, and L. E. Reukema.

The Space Charge that Surrounds a Conductor in Corona, by J. S. Carroll and J. T. Lusignan, Jr., Stanford University. (Presented by Mr. Lusignan.) Discussion by Messrs. L. F. Fuller, H. T. Plumb, J. S. Carroll, L. W. W. Morrow, R. J. C. Wood, and J. T. Lusignan, Jr.

Electric Oscillations in the Double-Circuit Transmission Line, by Yoshio Satoh, Graduate Student, Stanford University, 1926-27. (Presented by Dr. F. E. Terman.) Discussion by Messrs. R. J. C. Wood, E. R. Stauffacher, R. E. Pierce, D. I. Cone, H. T. Plumb, J. P. Jollyman, L. W. W. Morrow, and F. E. Terman.

Thursday's Technical Session

Mr. H. H. Schoolfield, Vice-President, North West District, presided over the session on Thursday morning, and the following papers were presented:

Transients Due to Short Circuits, by R. J. C. Wood and L. F. Hunt, Southern California Edison Company, and S. B. Griscom, Westinghouse Electric and Manufacturing Company. (Presented with slides by Mr. Wood.)

Equipment for 200-Kv. Systems, by J. P. Jollyman, Pacific Gas and Electric Company. (Presented by the author.)

Discussion of the above two papers was contributed by Messrs. F. R. George, H. Michener, P. B. Garrett, A. W. Copley, E. R. Stauffacher, R. J. C. Wood and J. P. Jollyman. Written discussions by Messrs. S. Barfoed and Roy Wilkins were read.

Static Stability Limits and the Intermediate Condenser Station, by R. D. Evans and C. F. Wagner, Westinghouse Electric and Manufacturing Company. (Presented by Mr. Evans, with demonstration by use of mechanical model.)

Synchronous Condensers, by P. L. Alger, General Electric Company. (Presented with slides by the author.)

The above two papers were discussed by Messrs. F. E. Terman, A. W. Copley, R. D. Evans, and P. L. Alger. Written discussions by Messrs. R. H. Park and M. W. Smith were read.

Friday's Technical Session

Mr. E. R. Northmore, Vice-President, Pacific District, presided at the closing session on Friday morning, and the following papers were presented:

Oscillographic Recording Apparatus for Transmission Lines, by J. W. Legg, Westinghouse Electric and Manufacturing Company. (Presented with slides and exhibition of equipment by the author.) Discussion by Messrs. A. W. Copley, R. D. Evans, and J. W. Legg.

High-Voltage Oil Circuit Breakers for Transmission Lines, by Roy Wilkins and E. A. Crellin, Pacific Gas and Electric Company. (Presented by Mr. Crellin.) Discussion by Messrs. L. C. Williams, R. J. C. Wood, F. C. Lindvall, R. W. Sorensen, E. K. Sadler, J. P. Jollyman, and E. A. Crellin. Written discussions by Messrs. H. E. Strang, Hilliard, M. M. Samuels, W. S. Edsall and Philip Sporn were read or abstracted.

Lightning Protection for Oil Storage Tanks and Reservoirs, by R. W. Sorensen, J. H. Hamilton, and C. D. Hayward, California Institute of Technology. (Presented by Professor Sorensen.)

Lightning Protection for Oil Tanks, by E. R. Schaeffer, Johns-Manville, Inc. (Presented with slides by the author.)

The above two papers were discussed by Messrs. R. J. Reed, M. E. Dice, G. O. Wilson, S. S. McKeown, J. T. Lusignan, Jr., J. H. Hamilton, C. D. Hayward, R. W. Sorensen, and E. R. Schaeffer. A written discussion submitted by Colonel Wilcox was abstracted briefly.

GENERAL MEETING

One of the most interesting features of the Convention was the general meeting held Wednesday evening, presided over by Mr. P. M. Downing.

In an address entitled *Electrical Communication*, Mr. Bancroft Gherardi, Vice-President and Chief Engineer, American Telephone and Telegraph Company, and President of the Institute, traced in a most interesting and instructive manner early developments in communication, and then gave brief accounts of the development of trans-continental telephony and trans-Atlantic radio-telephony.

Dr. Harris J. Ryan, Professor of Electrical Engineering, Stanford University, and Past-President of the Institute, delivered an address entitled *Possibilities of Future Electrical Development*. He discussed briefly the most important recent developments in electricity and related fields, and then predicted future developments in precise measurements by means of cathode rays, use of measuring facilities in applying X-rays, use of energy from the sun, prediction of location and intensity of earthquakes, protection of life and property from lightning, use of electricity in agriculture and transportation, power transmission, radio broadcasting, carrier-current control systems, navigation, etc.

These two addresses held the attention of the large audience of members and guests, and were deeply appreciated by all present, as they were delivered in such a manner as to be interesting to the ladies as well as to men with extended technical training.

ENTERTAINMENT FEATURES

The principal social event of the Convention was the banquet held on Thursday evening. Music was supplied by a hotel orchestra, and several Institute members under the leadership of Mr. J. S. Thompson, President of the Pacific Electric Manufacturing Company, provided entertainment which was enjoyed by all present. Ties which had resulted in the golf tournament, held on Thursday afternoon, in the competition for the low net, low gross, and kickers' handicap prizes were decided by putting contests conducted by Mr. W. B. Sawyer in the dining room during the banquet. The following golf prizes were then presented:

John B. Fisken cup, C. E. Heath.

Low Gross, Class A, two wooden clubs, G. B. Luther.

Low Gross, Class B, duffle bag, C. E. Heath.

Low Net, Class A, golf bag, W. D. Scott.

Low Net, Class B, set of six matched irons, L. M. Kilgore.

Kickers' handicap, first prize, leather golf coat, R. F. Monges. Second prize, sweater and hose, A. G. Jones.

The following prizes were presented to the winners of the ladies' putting contest which was held Thursday afternoon:

First prize, sweater, Mrs. W. D. Scott.

Second prize, stockings, Mrs. J. C. Henkle.

Other entertainment events provided were women's bridge tea at Pebble Beach Lodge on Tuesday afternoon, 17-mile drive on Thursday afternoon, and dancing Tuesday and Thursday evenings.

A number of excellent after-convention inspection trips to points of engineering interest were available, among which the following were suggested: 220 Kv. developments of Pacific Gas and Electric Company and Southern California Edison Company, Kings River Development of the San Joaquin Light and Power Corporation, substations supplying the San Francisco Bay district, Radio Corporation of America transmitting station at Bolinas Bay, Federal Telegraph Company factory at Palo Alto, Telephone Building at San Francisco, and the Harris J. Ryan High Voltage Laboratory at Stanford University.

At the close of the technical session on Friday morning, a motion was adopted expressing the sincere thanks of those present for the work of the Convention Committees which had made possible the fine success of the Convention. The personnel of the Convention Committees was as follows:

CONVENTION COMMITTEES

P. M. Downing, general chairman.
D. I. Cone, vice-chairman.
A. G. Jones, secretary.

Papers Committee

D. I. Cone, chairman, S. J. Lisberger, Paul Lebenbaum, W. C. Heston.

Publicity Committee

G. H. Hagar, chairman, G. Ross Henninger.

Entertainment Committee

E. A. Crellin, chairman, W. P. L'Hommedieu, W. B. Sawyer, A. V. Thompson, J. S. Thompson.

Registration and Transportation Committee

W. L. Winter, chairman, M. S. Barnes, P. B. Garrett, C. F. Benham, A. J. Swank, B. D. Dexter.

Arrangements Committee

W. R. Van Bokkelen, chairman, J. M. Buswell, A. M. Bohnert.

Future Section Meetings

Cleveland

An Engineering Yardstick Applied to Residence Lighting Equipment, by Ward Harrison, Director of Illuminating Engineering, National Lamp Works. Joint meeting with Illuminating Engineering Society at Nela School of Lighting, Nela Park, Cleveland. October 27.

Automatic Train Control, by Frank F. Fowle, Consulting Engineer. The meeting will be held in the Electric Rooms, Hotel Statler, at 8:00 p. m., November 17.

Pittsfield

To the North Pole and Back Again, by Floyd Bennett. November 1.

Steam Power Plants, by F. S. Collings. November 15.

New York

Radio Broadcasting, by M. H. Aylesworth, President, National Broadcasting Co., and

Radio Broadcasting as a Public Service, by Admiral W. H. Bullard, Chairman, Federal Radio Commission. October 14.

Talk by Senatore Marconi. Joint meeting with Institute of Radio Engineers. October 17.

Predicting the Future for New York, by Bancroft Gherardi, National President, A. I. E. E.; R. H. Shreve, Shreve and Lamb, and President, New York Building Congress; C. E. Smith, Consulting Engineer; L. S. Miller, President, New York, Westchester & Boston Ry. Co.; James S. McCulloh, President, New York Telephone Co., and John W. Lieb, Vice-President and General Manager, New York Edison Co. November 4.

(See further announcement following.)

New York Section Meetings Planned

Beginning with the October 14th meeting, which has scheduled for its program the subject of Radio Broadcasting, with the eminent speakers, M. H. Aylesworth, president of the National Broadcasting Company and Admiral W. H. G. Bullard, Chairman of the Federal Radio Corporation, the forthcoming meetings of the New York Section of the A. I. E. E. will be of no small importance and interest to scientific development. On October 17th, there will be a joint meeting with the Institute of Radio Engineers at which Senatore Marconi himself will be the speaker, the subject to be subsequently announced. This will be followed on November 4th by a meeting "predicting the future of New York," addressed by President Gherardi, on *The Probable Growth of New York City*; R. H. Shreve, President of the New York

Building Congress on *Architectural Requirements and Building Service*; C. E. Smith, Consulting Engineer, on *Urban Transportation*; L. S. Miller, President of the New York, Westchester & Boston Ry. Co. on *Suburban Transportation*; James S. McCulloh, President of the New York Telephone Company on *Telephone Service*; and John W. Lieb, President and General Manager of the New York Edison Company on *Light and Power Service*. The December 2nd meeting will have for its subject *Research and Research Men*, with Dr. W. R. Whitney, Director of the General Electric Research Laboratory and C. F. Kettering, General Director of the General Motors Research Laboratory as speakers. On January 13th, Alex Dow, President of the Detroit Edison Company will discuss matters concerning *Utility Interconnections* and Past-President Farley Osgood will address the meeting on *Interconnections of New York-Philadelphia Territory*. The dates of February 13 to 17 will be occupied by the activities of the Winter Convention of the Institute, followed on March 22nd by a meeting of the New York Section with the subject of *Lightning and Lightning Protection*, addressed by F. W. Peek, Jr.

International Radio Convention in October

The invitation of the United States Government to participate in the International Radio Telegraph Conference has been accepted by 50 of the 57 companies which have been invited. The conference will be held in Washington beginning October 4, according to an announcement issued Sept. 13 from the headquarters of the conference which have been established under the joint auspices of the Departments of State and Commerce. It is planned to bring up to date the international treaty agreement covering the use of radio.

The importance of this Conference has been repeatedly pointed out by the Secretary of Commerce, Herbert Hoover, who is head of the American delegation appointed by the President.

The I. E. C. Conference at Bellagio

The meeting of the International Electrotechnical Commission held at Bellagio, Italy, was opened September 4 by President Guido Semenza, followed by addresses by Prof. L. Lombardi, President of the Italian Committee, the Mayor of Bellagio, and representatives of two Italian ministries. Twenty-one countries were represented by 250 delegates, twenty-one of whom were Americans. There were 13 committees; three, headed by American delegates, on Nomenclature, Rating of Rivers, and Prime Movers. C. H. Sharp, C. E. Skinner and John Murphy (of Canada) were designated chairmen of committee sessions. Experts' papers on prime movers and switch rating were presented on Monday, Sept. 5. The Committee on Electric Meters completed its work and recommended the further study of problems relating to meter accuracy, insulation tests, and sizes, but no definite action was taken regarding the matter. The meeting of the Committee on Rating of Electrical Machinery was largely attended but no conclusions were reached. Insulating Oils, Voltages, and International Vocabulary Committees held interesting discussions.

The Conference completed sessions Sept. 12, the Americans presenting a bust of Benjamin Franklin to the Italian National Committee at a banquet held Sept. 10. The Advisory Committees completed their work and submitted reports to the Committee of Action, which were finally acted upon at a plenary meeting held at Rome Sept. 22. The Committee of Action met Sept. 12 and elected Prof. C. Feldmann, of Delft, Holland, President; Lt.-Col. K. Edgcumbe, Honorary Secretary; Guido Semenza, Honorary President. Sir Richard Glazebrook, General Secretary, resigned. The next meeting will be held at Stockholm in 1930. At a meeting of the officers of the I. E. C., Grand Reseau, Union Producers and Distributors, World Power Conference, International Tramway Union, Comite Consutative Int. Tel. & Tel., it was agreed to recommend the formation of a coordinating committee to meet at infrequent intervals to coordinate data and prevent overlapping of effort, the I. E. C. to function as a clearing house, since all of these bodies recognize the I. E. C. as the authoritative body for international electrical standardization. At a meeting presided over by A. F. Enstrom, of Sweden, the international standardization movement was informally discussed. A meeting of the Committee of Seven may be held in London the end of November 1927, such meeting being made necessary by the illness and resignation of Sir Archibald Denny. No further action in this matter will be required, however, on the part of the I. E. C. A new I. E. C. Advisory Committee was formed as follows: Electrical Installations on Shipboard; Secretariat, Great Britain. Other secretariats were assigned as follows: Italy, Voltages; France, Traction Equipment; Great Britain, Rating of Electrical Machinery. The United States was asked to subdivide the work of the Committee on Prime Movers into Thermal and Hydraulic. A large number of ladies was present at the official dinner to the delegates, given by the Italian Committee, at which addresses were delivered by Prof. L. Lombardi, Dr. A. E. Kennelly, Mr. John Murphy, Dr. Tivvey, of Australia, Mrs. C. H. Sharp and Madam Guido Semenza.

International Commission on Illumination Also Meets at Bellagio

The International Commission on Illumination met at Bellagio, August 31—September 3. Ten countries were represented by 67 delegates, of which seven were Americans. There were ten sessions, and forty-five papers on the subjects Automobile Headlighting, Factory Lighting, Photometric Methods, and International Definitions. Nine new technical committees were formed including those to discuss Diffusing Glassware, Signal Lenses, Daylight Motion Picture, Street Lighting, and Glare Research. Dr. Hyde, President since 1921, resigned, and C. C. Patterson, Director Research Laboratory at Wembley, England was appointed to succeed him. The next meeting will be held, United States, September 1928.

A 23-Day Midwinter Cruise

Our sister society, the American Institute of Mining and Metallurgical Engineers, is arranging for a midwinter cruise in the West Indies, leaving New York on January 25, 1928, on the 28,000-ton steamship *Lapland* and returning February 19, after visiting Havana, Kingston, the Panama Canal, Curacao, with a side trip to the oil fields of Venezuela, Puerto Cabello, La Guayra, and Bermuda. The cruise is specifically under the auspices of the Petroleum Division, but it may be found possible to offer some A. I. E. E. members opportunity to participate in this delightful 23-day midwinter cruise, (the cost of which will be from $250 up, according to accommodations desired).

Anyone interested will immediately notify Dr. H. Foster Bain, Secretary of the American Institute of Mining and Metallurgical Engineers, since, in the event of its being found possible to accept bookings from others, the first to register will be the first to be enrolled.

Annual Convention of Illuminating Engineers

The twenty-first annual convention of the Illuminating Engineers, to be held in Chicago October 11-14, inclusive, will be replete with features of scientific, commercial and practical interest. John F. Gilchrist, vice-president of the Commonwealth Edison Company, will give the address of welcome and there will be many Institute members represented on the program following. H. H. Higbie, Professor of Electrical Engineering at the University of Michigan, will deliver his president's address upon the morning of the opening day; Mr. Preston S. Millar will

report on his committee's work for the year on street lighting and, directed by G. H. Stickney, there will be a symposium on office lighting. Photometry and the photoelectric cell will be ably discussed as will also the lighting of railroad yards, airports and airways. Abundant provision will be made for the entertainment of visiting ladies.

Conference on Engineering Materials

From October 22 to November 13, a conference on engineering materials will be held in Berlin. The sponsors of this convention are the scientific engineering associations of Germany and the program will include approximately 200 papers delivered by both scientists and practical engineers. The papers will be given at the Technical University of Charlottenburg, while an exhibit of engineering materials will be arranged in the Neue Ausstellungshalle on the Kaiserdamm. Three distinct groups of engineering materials will be displayed; iron and steel, non-ferrous metals, and electrical insulation. Much of interest to the electrical profession will be included in the program of this convention.

Some Salient Facts About the National Safety Council

The National Safety Council, which held its sixteenth annual convention in Chicago, Sept. 26-30, is a non-profit making, non-partisan organization, whose purpose is the promotion of safety, sanitation and health in the industrial, public and home life of the American people. It is financed by its members, 4368 corporations, companies, partnerships, public officials, educators, organizations and individuals interested in the conservation of life, limb and property. It is the parent body of some sixty affiliated community safety councils scattered throughout the nation. Its officers and 1000 committeemen serve without financial compensation, meeting regularly to determine its policies and program. The organization serves as a national clearing house of accident prevention information, maintaining its headquarters at 108 E. Ohio St., Chicago, where a staff of more than 78 employees devote all of their time to safety work.

The first safety congress was held at Milwaukee, 1912, and a formal organization meeting was held in New York City in 1913, when the body was originally started as the National Council for Industrial Safety, a name which was changed inasmuch as the scope of the council broadened to include safety on the streets and highways, in other public places, at home, on the sea and in the air.

The first president was Robert W. Campbell, attorney for the Illinois Steel Company, a son-in-law of the late Judge E. H. Gary, who was one of the early safety leaders.

The first secretary was William H. Cameron, who is still with the organization, now serving as managing director. It was Mr Cameron who opened an office with only a handful of members and a few hundred dollars in cash. Last year the council spent more than $600,000 in its perpetual safety campaign and its affiliated units expended a similar amount.

The first congress held in Chicago was in 1914.

It is the contention of the council that practically all accidents, irrespective of where they occur, can be prevented through intelligent, organized safety work.

Industrial Bodies Join the A. E. S. C.

The Portland Cement Association and the American Gear Manufacturers Association have become members of the American Engineering Standards Committee, with direct representation on the Main and Executive Committees. F. W. Kelley, (Associate of the Institute since 1905), President of the North American Cement Association, represents the Association as a member of the A. E. S. C. Executive Committee.

A sectional committee is to be organized for the preparation of national specifications for mercury arc rectifiers, which work will include definitions, service conditions, load limitations, power factor, heating, short-circuit limitations, dielectric tests, insulation resistance, voltage regulation, efficiency and rating. It is undertaken as the result of requests of the American Railway Association and the American Institute of Electrical Engineers, the latter serving as sponsor for the sectional committee.

Standard values for the electrical and related constants of hard drawn aluminum conductors have recently been approved by the A. E. S. C. The standard was drawn up by a sectional committee under the sponsorship of the Institute, the subject being one which has been considered by the International Electrotechnical Commission as a basis of international agreement along the lines of the well-known "copper standards." The American standard for the conductivity of aluminum is appreciably higher than used in some of the foreign countries.

The following matters have been referred by the A. E. S. C. to its Electrical Advisory Committee for investigation and recommendations: 1. Rotating Machinery Standards. 2. Safety Code for Electrical Power Control—the subcommittee suggesting (a) That the A. E. S. C. request the sectional committees to provision five standards for the Electrical Safety Conference relating to such installation features as are acceptable and not already incorporated in the respective codes. (b) That the A. E. S. C. request the Underwriters Laboratories to give due consideration to each of these five standards with a view to incorporating in the Electrical Safety Code such as are appropriate to new standards of Underwriters Laboratories. (c) That the A. E. S. C. be instructed to advise the American Institute of Electrical Engineers and the National Electrical Manufacturers Association of the desirability of keeping in mind these particular standards of the Conference. 3. The approval of Rating Paragraphs of the A. I. E. E. standard No. 9 on Induction Motors and Induction Machines in General. 4. Electric Arc and Resistance Welding Apparatus, and the question of sponsorship for standards on these subjects.

The Electrical Advisory Committee is composed at present of two representatives each of the American Institute of Electrical Engineers, the Electric Light and Power group and the National Electric Manufacturers Association; and one representative each of the American Electric Railway Association, the American Railway Association, the American Society for Testing Materials, the Fire Protection group, the U. S. Bureau of Standards, the U. S. Navy Department and the U. S. War Department.

Provision has been made for including other industrial or technical organizations desiring representation.

ENGINEERING FOUNDATION

ENGINEERING RESEARCH

The word "research" is in danger of becoming an invidious term. At one extreme, it is being cheapened, like the word "engineer," by use as an artificial stimulant of unworthy causes—a too-common abuse nowadays in the exploitation of high-sounding words by self-seeking interests. At the other extreme, there is danger of what might be called research snobbery—a pose assumed by pedantic formalists who assert that only their kind of research is "pure." No less an authority than the president of Columbia University has stated that the word "research" is being used to cover a multitude of sins. He referred to members of a university who go through pretentious motions and glean little pepperkernels of insignificant fact in order to make much to-do over trivialities.

Some professors of chemistry or biology throughout the country would deny that there is such a thing as "engineering research." These pure scientists cherish a false pride of caste and an almost religious prejudice against anything associated

with that they call "trade." To them, so gross and commercial an application as engineering could never be associated with so sacred a word as "research." Their convictions are so closely wrapped up with self-aggrandizement and what the preacher calls "vanity of vanities" that there is not much hope that they will broaden their views until the sense of the ridiculous overtakes them. Happily, but few scientists continue to harbor such convictions. Cooperation between scientists and engineers has become intimate and mutually helpful.

Engineering research has fairly well crystallized out as a legitimate and meritorious activity. It has passed through its period of adolescence and nose-to-the-grindstone, and is now on a scientific and objective basis. Mercenary considerations have been mellowed by altruism and a professional spirit—much as is medical research, for a concrete analogy An engineer experimenting scientifically in a research laboratory on the properties of metals is just as truly serving mankind and alleviating its problems as any bacteriologist in the Rockefeller Institute, and is just as truly disclosing laws of nature as any professor of chemistry who applies Gibbs' phase-rule to an untried combination of elements.

Much engineering research is done of course, for commercial profit, more or less directly. A corporation such as the General Electric Company cannot afford to engage a Langmuir or a Steinmetz unless there is some indirect advantage in prospect. But an increasing number of industrial corporations are taking a long, broad view of what constitutes profit. Still more detached and altruistic is the research work of such an institution as the Engineering Foundation.

This Foundation was the creation of Ambrose Swasey, eminent engineer, telescope builder and machine-tool maker of Cleveland, with the aid of friends in the engineering societies. Having gained a fortune in engineering, Mr. Swasey determined to benefit his profession in a lasting and idealistic way. Instead of establishing a foundation which would bear his name but to which contributions of other philanthropists would be unattracted, he devised the happier plan of placing funds in charge of the four founder engineering societies in order to encourage and elevate engineering research of a kind not otherwise likely to be carried on. This generous gift to establish the Engineering Foundation was intended as the beginning of a trust for the country's engineering community—a trust which would grow to great size by additions from other persons interested in, or profiting by, engineering. And who does not profit by engineering?

P. B. McDonald.

A New Pamphlet on the Testing of Insulation Materials

The American Society for Testing Materials has recently issued a special reprint pamphlet covering methods for testing insulating materials. This pamphlet covers all such methods prepared by Committee D-9, as well as the annual report of the committee presented at the June meeting of the Society, French Lick, Ind. In addition to the Standards and Tentative Standards now in force, there is included as an appendix to the report a description of the latest method of making the life test of transformer oils. The pamphlet contains 130 pages, and is now available for distribution at the following rates: 1 to 9 copies, 80 cents; 10 to 24 copies, 70 cents; 25 copies and over, 65 cents. Address American Society for Testing Materials, 1315 Spruce Street, Philadelphia, Pa.

Overhead Systems Reference Book

The Overhead Systems Reference Book of 1927 has been published by the National Electric Light Association and was prepared by a special committee of the Overhead Systems Committee of the National Engineering Section of that association. This work is successor to the handbook on overhead line construction which was published in 1914. As stated in the preface, the purpose of this reference book is to present in one volume a description of the apparatus, material, methods and principles involved in overhead line construction and the tabulation of necessary formulas for the electric and mechanical solution of various transmission and distribution problems.

The book is issued as engineering information and is not to be considered as a book of rules and regulations nor an attempt to create standards or specifications to govern construction methods. The formulas and data presented have been taken from authoritative sources and it is believed they will prove a valuable aid in the solution of specific problems.

The contents include an extensive list of definitions and general information and the following chapters: Wood Poles, Preservative Treatment and Concrete Poles; Steel Poles, Towers and Substation Structures; Properties of Materials; Insulators; Transformers and Regulators; Protective Apparatus; Street Lighting; Electrical Calculations; Mechanical Calculations of Transmission and Distribution Lines; Methods of Construction for Low and Medium Voltage Lines; Meteorological Data, Tree Trimming and General Safety Suggestions.

The book is highly illustrated and contains a comprehensive index. It is 8½ by 11 inches in size, bound in flexible leather with gilt edges and rounded corners and contains a wealth of information which otherwise would be available only by consulting scattered literature through a great number of publications.

New Bulletin to be Issued by U. S. Forest Service

The United States Forest Service has in press a bulletin entitled *Forests and Water in the Light of Scientific Investigation*, which contains "a summary and review of the world's scientific literature on the subject of the influence of forests on climate, streamflow, floods, and erosion," and "a very extensive bibliography on these subjects." The contents of this bulletin, which is approximately 70 pages in length, were published several years ago as part of the Final Report of the National Waterways Commission, and are now being made available in convenient form as a result of the demand for information on flood control problems.

Copies of the bulletin may be secured by addressing the Forest Service, Washington, D. C.

The Industrial Transition in Japan

Maurice Holland, Director of the Division of Engineering and Industrial Research of the National Research Council, has just brought out a small edition de luxe giving in condense form a report of his investigation of the industrial situation in Japan while attending the Pan Pacific Science Congress as a representative of the United States Government, the National Research Council, and other national bodies. The book is of pocket size, and contains 52 pages of printed matter descriptive of pearl culture, Japanese fisheries, Japanese industrial research, civil aviation in Japan, the silk industry, general impressions and conclusions and an industrial map of Japan in interesting though concise form. Mr. Holland's work is sponsored by the Japan Society as well as the Research Council. The book is available through the publishers, the Federal Printing Company, New York, N. Y.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any changes in mailing or business address, thus

relieving the member of needless annoyance, assuring the prompt delivery of Insitute mail, accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

Frank Green, 984 Charles River Rd., Cambridge, Mass.
Raymond W. Klotz, Cutler Hammer Mfg. Co., Milwaukee, Wis.
F. W. Molitor, General Delivery, Los Angeles, Calif.
Richard T. Quass, 610 Cornell St., Perth Amboy, N. J.
Thomas Sheehan, 2126 Vyse Ave. at 181st. St., New York, N. Y.
E. R. Shepard, 5522 Conneticut Ave., Washington, D. C.
Joseph F. Smith, The L. E. Myers Co., Chicago, Ill.
Richard A. Towers, 455 Lafayette Place, Culver City, Calif.
P. A. Bertrand, Grays Harbor Ry. & Lt. Co., Aberdeen, Wash.
Hiram Stanley Fox, 33 Gordon Ave., Atlanta, Ga.
George A. Grimm, 3501 S. Crawford Ave., Chicago, Ill.
Geo. J. Hollander, 547 S. Main St., Torrington, Conn.
Perry L. Jewett, 5th & Washington Sts., Santa Rosa, Calif.
Charles W. Magee, 72 Humphrey Ave., Bayonne, N. J.
Arne S. Mossige, 757 57th St., Brooklyn, N. Y.
Victor W. Sparr, 8830 Railroad Ave., Corona, N. Y.

PERSONAL MENTION

W. E. North is now with the Volunteer Portland Cement Co. in the capacity of mechanical and electrical engineer for the building of its new Cement Plant at Knoxville, Tenn.

J. M. Hipple, who was manager of the Westinghouse Electric & Mfg. Company's Motor Engineering Department takes charge as works manager with the promotion of Mr. Wilson.

J. B. Bassett of the New York office of the General Electric Company has been named Executive Engineer of its New York District.

T. F. Barton of the Central Station Engineering Department of the General Electric Company at Schenectady, has been made engineer of the New York District, with headquarters at 120 Broadway, New York.

R. L. Wilson until recently works manager of the East Pittsburgh Works of the Westinghouse Electric & Manufacturing Company is now assistant to the vice-president and general manager.

Alfred Alsaker, chief engineer of the Delta-Star Electric Company, Chicago, Ill., sailed September 11 for a six-weeks' visit to Norway, France, and Italy, to investigate the high-voltage developments on the Continent.

H. Zangler, electrical engineer of the Burma Oil Company is now engineer and superintendent of the Tropical Oil Co. at its El Centre (Columbia) field, which has been in existence only a few years. He will remain in this service for two years.

E. A. Thornwell has been appointed Representative of the Corning Glass Works, with headquarters in the Candler Building, Atlanta, Ga., to handle only the sales of Pyrex Power Insulators in the States of Georgia, Florida and Tennessee.

George N. Brown, formerly vice-president and sales manager of the Pittsburgh Transformer Company, has joined the Ohio Brass Company as Manager High Tension Sales. Until the World War Mr. Brown was with the New York State Railways.

Robert A. Millikan, executive head of the California Institute of Technology, Pasadena, Calif., and Director of the Norman Bridge Laboratory, on September 6, 1927 received the honorary degree of Doctor of Science from Leeds University, Leeds, England.

James R. Werth, is now head of the Power Bureau of the Florida Power & Light of Miami. Major Werth previously served in the Construction Division of the Army and with the H. M. Byllesby and the American Gas & Electric properties.

Doraf W. Blakeslee, for the past eight years electrical engineer of the Jones & Laughlin Steel Corporation, Pittsburgh Pa., is now illuminating engineer for the Pittsburgh Reflector Co. Capt. Blakeslee has had 17 years' experience with civil, mechanical, and electrical experience.

J. M. Oliver, formerly operating engineer of the Alabama Power Company, has become operating manager of the Georgia Power Company, taking over the work previously handled by Mr. Bennett. Before becoming operating engineer Mr. Oliver served in almost every department of that company.

R. H. Goodwillie, manager of the Otis Elevator Company, Yonkers, was elected treasurer of the National Electric Manufacturers Association by the Executive Committee. Mr. Goodwillie succeeds J. W. Perry, who has resigned from active business.

Carl E. Johnson, vice-president of the U. S. Electrical Mfg. Co. and president of the U. S. Industries, Inc., of Los Angeles, has resigned, disposing of his holdings in both companies. He has been an officer and director since their inception, and for over twenty years has been intimately identified with the electrical manufacturing industry of Southern California.

Giuseppe Faccioli has been appointed associate manager of the Pittsfield Works of the General Electric Company. Since his arrival in the country 25 years ago, Mr. Faccioli has progressed steadily, much of his early training was acquired through his association with William Stanley. He is a natural born leader and untiring in his endeavors to stimulate interest in the profession.

Gordon Thompson has been made assistant chief engineer at the Electrical Testing Laboratories, having recently returned from China where he spent seven years as professor of electrical engineering at Nanyang University, Shanghai. During that time he also acted as consulting engineer for the Mission Architects' Bureau of that city. Mr. Thompson was engineer in charge of electrical laboratories at the Electrical Testing Laboratories for ten years before going to China.

C. E. Bennett, former manager of the Electrical Department of the Georgia Railway & Power Company has now become general engineer in charge of the Engineering Department. Mr. Bennett has been with the company for over 15 years and his engineering achievements parallel the development of the company. He was electrical engineer for the construction of the company's first hydroelectric development, the Tallulah Falls power plant, and was also engineer in charge of the Tallulah high-voltage and the Newman and Lindale transmission lines. He designed the Boulevard, the Spring Street, Walton Street, Edgewood Avenue, Stewart Avenue and Moreland Avenue Substations.

Obituary

Frederick Ludwig Baer, who joined the Institute in 1907, died in Chicago the evening of September 6th, as the result of an automobile accident. He was born in Wilkes Barre, Pa., in 1880, and was a graduate of Notre Dame University, Notre Dame, Ind., after a preparatory course at Mt. St. Mary's College, Emmittsburg, Md. For many years he has been with the Automatic Electric Company as assistant chief engineer. Just prior to joining the Institute he was appointed superintendent in charge of equipment for all exchanges in and near San Francisco operated by the Home Telephone Company. In all of his endeavors, he was counted an extremely worthy worker. At the time of his death he was chief engineer of the International Telephone Sales and Engineering Corp., Chicago.

Frank Forrester Thompson, Professor of Electrical Engineering at Rutgers College, died at Lewiston, Pa., after a fall from the window of the Coleman Hotel. He was in his 57th year. His native town was Milroy, Pa., not far from Lewiston, and he was the son of the Rev. and Mrs. Samuel Thompson. In 1894 he graduated from Princeton and was from 1897 to 1898 Instructor in Physics at Union College. From 1898 to 1901 he was at Pennsylvania State College as Instructor in Electrical Engineering, entering upon his service as Instructor in Electrical

Engineering at Rutgers University in 1903. In 1906 he became Assistant Professor of Physics, in which capacity he served until 1908, when he was chosen Professor of Electrical Engineering. Professor Thompson became an Associate of the Institute in 1909.

PAST SECTION MEETINGS

SECTION MEETINGS

Portland

Boat trip with various other engineering societies in Portland, under the auspices of Oregon Technical Council. August 2.

Saskatchewan

Dinner Meeting in honor of Bancroft Gherardi, National President, A. I. E. E. August 18. Attendance 80.

Spokane

Business Meeting. The following officers were elected: Chairman, L. R. Gamble; Vice-Chairman, Joseph Wimmer; Secretary-Treasurer, James B. Fisken. May 27. Attendance 15.

Vancouver

The Development of Modern Communication, by Bancroft Gherardi, National President, A. I. E. E. Reception. August 23. Attendance 47.

A. I. E. E. Student Activities

STUDENT ACTIVITIES AT PACIFIC COAST CONVENTION

The first afternoon of the Pacific Coast Convention, held at Del Monte, Calif., September 13-16, was devoted to student activities in accordance with plans made previously by Professor R. W. Sorensen, Chairman of the Committee on Student Activities of the Pacific District, and the Convention Committee.

A luncheon meeting of Student Branch Counselors and Chairmen was held at 12:30 p. m. Of the seven Branches in the District, five were represented by their Counselors, and faculty representatives of the other two were present. All Branch Chairmen were present.

Immediately after the luncheon, a Conference on Student Activities was held. Professor R. W. Sorensen presided. He requested each of the Counselors and Branch Chairmen to stand and announce his name and his Branch affiliation. Mr. P. M. Downing, Chairman of the Convention Committee and retiring Vice-President, Pacific District, and Mr. E. R. Northmore, Vice-President, Pacific District, were introduced and addressed the audience briefly. Mr. D. I. Cone, Vice-Chairman of the Convention Committee, and retiring Chairman of the San Francisco Section, welcomed the members and guests on behalf of the Section. He then read a letter from Dr. C. E. Magnusson who expressed his regrets that he was unable to be present, and gave an excellent summary of the advantages to be gained by students through such connections with the Institute.

President Gherardi said the students of today will form the backbone of the electrical engineering profession of tomorrow, and said the provision for Student Branches is very beneficial to the students and to the Institute.

National Secretary Hutchinson gave a brief summary of the development by the Institute of plans for meeting its duties to the students, and mentioned the recent changes in policy which provide for the appointment of a Counselor of each Branch, the organization of District Committees on Student Activities, and the publication of a Student Activities department in the JOURNAL.

At the request of Chairman Sorensen, Professor T. H. Morgan, Counselor of the Stanford University Branch, gave a brief report upon the Student Convention held at Stanford January 14, 1927, in which three Branches participated.

In reply to a question regarding the Student Activities department in the JOURNAL, Assistant National Secretary Henline explained that this department had been inaugurated in the January 1927 issue in order to provide a definite location in the JOURNAL for items on the activities of Branches, Counselors, and District Committees as well as other items of interest in this field and some of the worthier student papers. This plan has been carried out in an experimental manner, without any specific appropriation, in order to gain experience which will assist in the development of a definite policy for the future.

The Student Technical Session followed immediately after the close of the general conference, and the following papers were presented briefly:

CALIFORNIA INSTITUTE OF TECHNOLOGY

A Method of Measuring Extremely High Resistances and Some Results Obtained with Porcelain Suspension Insulators, by Frey Hamburger. (Presented by Mr. W. A. Lewis.)

Wiring at the California Institute of Technology, by L. G. Fenner. (Presented by Mr. J. W. Thatcher.)

Production of High Vacuua, by R. S. Thacker. (Presented by the author.)

Some Recent Experiments With the Vacuum Switch, by F. C. Lindvall. (Presented by the author.)

Some Factors Affecting Flashover Voltage of Insulators, by W. A. Lewis. (Presented by the author.)

STANFORD UNIVERSITY

Harmonic Phase Orientation, by R. D. Boynton and A. V. Pering. (Presented by A. V. Pering.)

The High-Voltage Oscillator, by Bradley Cozzens. (Presented by the author.)

High-Voltage Phenomena in the Atmosphere, by M. A. Lissman. (Presented by Mr. J. T. Lusignan, Jr.)

Super-Regeneration, by George Hulstede. (Presented by Dr. F. E. Terman.)

Tuned Power Lines, by Hugh Skilling. (Presented by the author.)

STATE COLLEGE OF WASHINGTON

The Evolution of the Thermionic Vacuum Tube, by H. R. Meahl. (Not presented, as no one from this institution was present.)

UNIVERSITY OF CALIFORNIA

Design of an Electromagnetic Absorption Dynamometer, by Daniel Silverman and T. L. Mayes. (Presented by Mr. Silverman.)

UNIVERSITY OF SOUTHERN CALIFORNIA

Tests of a 9375 Kw. Water-Wheel Generator, by James Hendry. (Presented by the author.)

Tests of a New Type of Constant-Current Regulator, by Turner White and A. E. Sayler. (Presented by Mr. White.)

UNIVERSITY OF UTAH

Power Factor Characteristics of the Fynn-Weichsel Motor, by V. S. Thomander and O. C. Haycock. (Presented by Mr. F. W. Maxstadt, California Institute of Technology.)

UNIVERSITY OF WASHINGTON

A Table of $B^{1.6}$ and n $B^{1.6}$ and an Alignment Diagram for the Graphical Solution of the Steinmetz Equation for Hysteresis Loss, by H. J. Scott. (Presented by Mr. C. M. Briggs.)

The World's Largest Automatic Hydro-Electric Station, Constructed for the Pulp and Paper Industry, by W. L. Thrailkill and R. H. Crosby. (Presented by Mr. C. M. Briggs.)

The Five Hundred Mile Transmission Line with Distributed Synchronous Condensers, by C. M. Briggs. (Presented by the author.)

Mimeographed abstracts of the above papers were distributed prior to presentation. Authors were allowed ten minutes for the presentation and discussion of each paper. Some time was allowed for general discussion of each paper, and most of them were discussed briefly. The session was very interesting to both students and practising engineers.

At a meeting of the Counselors held later, Professor Philip S. Biegler, University of Southern California, was elected Chairman of the District Committee on Student Activities, and Professor T. H. Morgan of Stanford University was elected Secretary.

BRANCH MEETINGS

University of California

Business Meeting. August 24. Attendance 34.

Kv-a. and Demand Metering, by W. N. Lindblad, Pacific Gas and Electric Co. September 7. Attendance 65.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is adminstered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES AUG. 1-31, 1927

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

THEORY OF MACHINES.

By Louis Toft and A. T. J. Kersey. Lond. & N. Y., Isaac Pitman & Sons, 1927. (Engineering degree series). 408 pp., illus., diagrs., 9 x 6 in., cloth. $3.75.

This textbook on the theory of machines covers the course required of engineering students in English universities. Stress is laid upon fundamental principles and a large number of examples illustrating their practical application are provided.

STUDIES IN OPTICS.

By A. A. Michelson. Chicago, Univ. of Chicago Press, 1927. (Science Series). 176 pp., illus., plates, 8 x 5 in., cloth. $2.00.

A resumé of Dr. Michelson's own investigations, treated somewhat as in "Light Waves and Their Uses," but with more attention to the theoretical side and with the inclusion of a number of investigations made since that book was published. Although the work described involves a general acquaintance with the calculus, it is so presented that those without it can obtain a fair knowledge of the experimental method and the results obtained.

The book brings together material that has hitherto been available only in scattered articles and presents it concisely with as little technical detail as possible. It will be of interest to educated laymen, as well as to specialists.

SPECTROSCOPY, v. 2.

By E. C. C. Baly. 3rd edition. N. Y., Longmans, Green & Co., 1927. (Textbooks of physical chemistry). 398 pp., illus., tables, 9 x 6 in., cloth. $6.00.

Since the first volume of this edition appeared in 1924, the advance in spectroscopy has been so rapid that Professor Baly has found it necessary to expand the work to four volumes, instead of the two originally planned. The present volume gives an account of interferometer methods, with chapters on methods of illumination, the nature of spectra, fluorescence and phosphorescence, and the photography of the spectrum. It is distinguished by its attention to detail in describing the technique of spectroscopy and by its comprehensiveness.

PRESSURE AIRSHIPS.

By Thomas L. Blakemore and W. Watters Pagon. N. Y., Ronald Press Co., 1927. (Ronald Aeronautic Library). 311 pp., illus., diagrs., tables, 9 x 6 in., cloth. $8.00.

Discusses the design and construction of airships in which the shape of the envelope is maintained by the pressure of the gas in it. Mr. Blakemore is responsible for the section upon non-rigid airships, Mr. Pagon for that upon semi-rigid types.

Each section considers the general characteristics of the airships, describes the various types, explains the design and construction of hulls, suspensions, controls, cars and other parts. Erection, inflation and rigging are described, and many technical data are given. The book aims to provide the information wanted by students, engineers, designers and builders. It is based upon the practical experience of the authors.

NEL I° CENTENARIO DELLA MORTE DI ALESSANDRO VOLTA, 1827-1927. Special no. of L'Energia Elettrica, issued by Unione Nazionale Industrie Elettriche. [Milan, 1927]. 327 pp., illus., 12 x 9 in., paper. Price not quoted.

In commemoration of the centenary of Volta, a special number of "L'Energia Elettrica" has been issued under the auspices of the Unione Nazionale Fascista Industrie Elettriche. The memorial is an attractive volume containing photographs of an original voltaic pile, of Volta's residences, and of a painting of Volta. The text comprises twenty-one papers by prominent

Italian electricians, among which are reviews of Volta's scientific work, of electrostatics during the past one hundred and fifty years, and of developments in the various branches of the science.

MEMOIRES ET RAPPORTS TECHNIQUES, No. 5. By Institut National Roumain pour l'Etude de l'Aménagement et de l'Utilisation des Sources d'Energie.

Considerations sur l'Auto-Excilation des Alternateurs Branchés aux Lignes de Haute Tension. By Georges Petresco. Bucharest, 1927. 29 pp., diagrs., 9 x 6 in., paper. Price not quoted.

This paper, presented at the recent International High-Tension Conference, is a contribution upon the problem of the self-excitation of alternators connected to high-tensions lines. The nature of the phenomenon is explained, a detailed method is given for determining its effect in advance, and its dangers are discussed.

MEMOIRES ET RAPPORTS TECHNIQUES, No. 2 and 4. By Institut National Romain pour l' Etude de l 'Aménagement et de l'Utilisation des Sources d'Energie. No. 2, Puissances Réactives et Fictives: No. 4, Les Différentes Opinions et Conceptions Concernant la Notion de Puissance Réactive en Régime non Sinusoidal.

By C. Budeanu. Bucharest, 1927. No. 2, 360 pp., illus., diagrs., 9 x 6 in., paper. No. 4, 47 pp., 11 x 9 in., paper. Prices not quoted.

Number two is an extensive study of reactive power from a theoretical and practical viewpoint. The general properties of the apparent and reactive quantities in electric circuits are treated theoretically, the effects of reactive power are discussed and methods of remedying the effects are described. Methods of metering power which take account of reactive power are discussed. Both sinusoidal and non-sinusoidal currents are considered. The author endeavors to reconcile varying opinion and to arrive at uniform general principles in concepts of various aspects of the problem.

Number four is a pamphlet summarizing the various concepts of reactive power in non-sinusoidal currents which have been formulated by various prominent electricians, accompanied by those of the author.

LUBRICATION AND LUBRICANTS.

By Leonard Archbutt and R. Mountford Deeley. Fifth edition. Lond., Charles Griffin & Co.; Phila., J. B. Lippincott Co., 1927. 650 pp., illus., tables, 9 x 6 in., cloth. 36 s.

This treatise upon lubricants has long been a standard and is too well known to need an introduction. This edition, the first revision since 1912, has been largely rewritten and rearranged, in the light of recent investigations. A general theory of solid friction is now presented, much new matter on the theory of viscous lubrication has been incorporated, and the chapters on lubricants and their examination have been thoroughly revised and enlarged. The chapter on frictional testing of lubricants has been rewritten. The information on lubricators and on the design of bearings has been much expanded. A chapter on the recovery of lubricating oil has been added.

DIE KONDENSATWIRTSCHAFT.

By Hans Balcke. Mün. u. Ber., R. Oldenbourg, 1927. 219 pp., illus., diagrs., 9 x 6 in., paper. 10,-r. m.

The condenser, as viewed by Dr. Balcke, is no longer merely an apparatus for precipitating waste steam under certain conditions but instead is today also a valuable apparatus for preparing feed-water and a preheating plant for all purposes. Condenser engineering begins at the exhaust of the engine and ends only with the injection of prepared, heated feed-water into the boiler.

This book discusses condenser practise in stationary steam plants as a self-contained department of heat engineering. It assists the power-plant engineer to evaluate his plant from the viewpoint of heat economy and to utilize waste heat to the fullest degree. It takes up the various units of the power-plant, points out the losses of heat and energy in each and shows how to avoid or utilize them. It teaches that condensation practise is in fact a special branch of chemical technology and pleads for consideration of its problems from a modern point of view.

HEATING AND VENTILATING.

By Charles L. Hubbard, revised by Wm. H. Severns. Chic., American Technical Society, 1927. 230 pp., illus., tables, 9 x 6 in., cloth. $3.00.

An elementary practical textbook on the design and construction of heating and ventilating plants.

ANLASSVORGANGE IN ABGESCHRECKTEN KOHLENSTOFFSTAHLEN.

By L. Traeger. (Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, Heft 294) Berlin, V. D. I. Verlag, 1927. 20 pp., illus., diagrs., 12 x 9 in., paper. 3,80-r. m.

In this pamphlet the changes in length of hardened carbon steels during annealing are investigated and compared with the changes in other of their properties. The various methods of research are described, their results discussed critically and an explanation of the process of annealing given. This is not, according to the author, in a gradual decomposition of the martensite, but consists of three transformations at definite temperatures, each accompanied by changes in length, structure, electrical resistance, solubility and strength. These transformations are explained and methods for determining the proper temperature and time in annealing practise are given.

DRAFTING FOR ENGINEERS.

By Carl Lars Svensen. N. Y., D. Van Nostrand Co., 1927. 363 pp., illus., diagrs., tables, 9 x 6 in., cloth. $2.75.

A comprehensive textbook which covers not only general methods and fundamental principles but also provides material for special study of architectural, structural and electrical drafting. Over 300 problems are included.

EXPERIMENTAL ELECTRICAL ENGINEERING, v. 2.

By V. Karapetoff. 3rd edition. N. Y., John Wiley & Sons, 1927. 620 pp., diagrs., 9 x 6 in., cloth. $5.00.

This second volume of Professor Karapetoff's text on laboratory practise is intended for more advanced students than was the first. Some chapters of it are sequels to the more elementary treatments of certain topics in volume one, others are introduced for the first time here.

Among the subjects included are various tests of synchronous and induction machines, transmission and distribution lines, polyphase systems, controllers, and mercury-vapor and thermionic rectifiers, as well as methods for wave analysis and high frequency measurements. The book is primarily for the student, and the educational usefulness of the methods is kept in view, without, however, lessening the value for the practising engineer. References for further study are supplied liberally.

FOREMANSHIP AND SUPERVISION.

By Frank Cushman. N. Y., John Wiley & Sons, 1927. 238 pp., illus., 8 x 5 in., cloth. $2.50.

The author discusses the value of the conference as a means of education, the methods of holding conferences, the duties and qualifications of those leading them, and the results that may be expected. The use of conferences to train foremen and to train teachers and supervisors of vocational education is illustrated in detail.

GENERAL PHYSICS.

By Henry Crew. 4th edition. N. Y., Macmillan Co., 1927. 674 pp., illus., diagrs., 9 x 6 in., cloth. $4.00.

The author's purpose is the presentation, in an elementary manner, of the facts that are most essential for presentation to first-year and second-year college students, with the philosophy which most simply connects them. The book is a clearly written text-book, in which the attention of the student is held by the way in which the principles are illustrated by phenomena with which he is familiar. The revision has incorporated the results of recent discoveries in physics.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th day of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL DESIGN ENGINEER, with mature judgment, for manufacturer of X-ray and medical apparatus. Must be thoroughly competent to undertake basic new design work in this field and must have originality and sufficient executive ability to get things done. Opportunity. Salary, about $3600 a year to start. Apply by letter. X-3403-C.

MEN AVAILABLE

GRADUATE ELECTRICAL ENGINEER, 24, holding B. S. in E. E., and S. M. in E. E. (M. I. T. 1926), including graduate work in electric traction, railway engineering and public utility administration, desires permanent connection, preferably in heavy electric traction field. Experience includes fourteen months shop and design work with electrified railroad. Highest references. Salary commensurate with training and ability. Employed at present, but available on short notice. C-3462.

ELECTRICAL DESIGNER, 27, single, ten years' experience in design of central stations, substations (high and low tension), railway substations and overhead and underground distribution systems. Desires position with public utility. Location immaterial. Available on two weeks' notice. B-8628.

SALES ENGINEER, 43, married, sales work, mechanical or electrical, in New York or Westchester County. C-557.

EXECUTIVE ENGINEER, 32, married, mechanical engineer graduate, twelve years' diversified work industrial plants, large and small. Experienced in design, manufacturing, construction and management. Now staff member of prominent consulting and management engineering corporation. Desires position in East not requiring traveling. C-43.

RADIO ENGINEER, desires radio technical position or perhaps sales in radio, 22, single. Varied experience in radio testing, construction of test boards, experience in general wiring and repair work, experience in engineering research at technical school. New York City, vicinity Southern New England, Eastern New York preferable, or elsewhere. C-3300.

ELECTRICAL ENGINEER, E. E., ten years' experience in the design and manufacture of electrical apparatus. Age 34. Now employed, but would like to make a change. Licensed in New York State. C-3498.

ASSISTANT EXECUTIVE, PRODUCTION ENGINEER OR MANAGER, eleven years constructive record in mechanical and electrical engineering and management; experienced on accounting and production, including plant planning, layout, production control, budgeting, wage incentives, cost reduction. Technically trained, interested in business and management. Capable of reorganizing or managing operations efficiently and economically. Age 32, married. B-9676.

JUNIOR ELECTRICAL ENGINEER, graduate in E. E. from large university, desires permanent position with public utility or manufacturing company dealing in electrical material. Age 22, graduated in 1926, G. E. test course, specializing in motors, transformers and street lighting equipment. Willing to travel, prefer location on Pacific Coast. Available at once. C-3320-77-C-3.

GRADUATE ELECTRICAL ENGINEER, desires position as superintendent of construction or maintenance engineer in large operating company. Two years General Electric test, two years assistant superintendent in large manufacturing plant, fourteen years erecting engineer supervising large electrical construction work both in United States and foreign countries. Desires permanent location. C-3483.

ELECTRICAL ENGINEER, age 28, married, B. S. in E. E., and E. E., five years' experience test supervision with public utility, one year's experience teaching. Editor, executive, statistician, organizer. Desires position with industrial organization. C-1346.

JUNIOR DISTRIBUTION ENGINEER, 27, good technical and business training, seven years public utility field construction, operation, inspection and distribution. Experienced in three phase change over and other reconstruction work. Location immaterial. Available on two weeks' notice. C-3516.

ELECTRICAL ENGINEERING GRADUATE, 25 years old, Associate Member of A. I. E. E., three years' experience with engineering and industrial motor control problems in the sales and engineering departments of a large manufacturing company. Desires position with a growing contracting, manufacturing, public utility, or other concern handling electrical equipment. Location, United States. C-3530.

MECHANICAL AND ELECTRICAL ENGINEER, Cornell graduate, 18 years' experience, including efficiency engineering for large industrial (paper mill) along steam and power production lines; combustion studies, boiler-house rehabilitation, etc. Industrial power sales engineer for utility. Prior to foregoing, supervision electrical installations for large electrical manufacturer while stationed in Eastern city. B-6764.

ELECTRICAL ENGINEERING GRADUATE, 1925, B. S. in Electrical Engineering, 27, one year G. E. test and one year distribution engineering experience with large, western public utility, also had experience meter department. Desires permanent position with public utility. Can furnish best of references. Location, immaterial. C-3536.

ELECTRICAL ENGINEER, A. I. E. E., 27, married, graduate electrical engineer, four years' engineering experience; one year design and layout of substations; three years general engineering work in electrical engineering department of big public utility, including construction, system operation; desires new connection with contracting, managing or holding company or utility. Location preferred, Eastern States, preferably New York City. C-3534.

ELECTRICAL ENGINEER, technical graduate, Westinghouse test, over three years' experience in power stations, age 29, married. Desires position as Electrical Inspector, Hydro Plant Engineer or System Relay Engineer. B-8367.

GRADUATE ELECTRICAL ENGINEER, desires position with public utility, consulting engineer or with bank, where organizing and executive, as well as engineering ability is required. G. E. Test, four years with public utility, five with consulting engineering firm. Thoroughly familir a with valuation and engineering work. B-389.

GRADUATE ENGINEER, B. S. in E. E. in 1924, 27, single, with wide technical training, two years public utility appraisal work. Business and executive ability. Desires position as assistant to executive in utility or manufacturing business, or in consulting engineering office. Very much interested in developmental and experimental work on processes or patents. B-9528.

ELECTRICAL ENGINEER, TEST, OPERATING, CONSTRUCTION, 33, married, 8 years' laboratory, research, testing of electrical measuring apparatus, relays and watt hour meters. Have 5 years' varied experience in estimating, designing and constructing of sub-stations and power plants, the operation of sub-stations, electric shovels, mine equipment, locomotives and mill equipment. Available 3 months. Location U. S. A. or foreign. Speak Spanish. Invite correspondence. C-3549.

RECENT GRADUATE, B. S., (E. E.), M. I. T. 1927, honor student, 21, single, desires a position either in business, engineering, or teaching field. Good habits, honest, conscientious, excellent references. Location anywhere. Available immediately. C-3550.

YOUNG MAN, 29, electrical engineer, M. A. in physics, 4 years teaching, 1 year research experience, would like teaching or research position with future. Salary no object. B-3411.

GRADUATE ELECTRICAL ENGINEER, 27, single, five years of experience in transmission and substation construction in the West, eight months in industrial plants. Desires position along engineering lines, and opportunity for permanent employment. Available one month. Location anywhere. C-3564-78-C-3.

ELECTRICAL ENGINEER, Cornell graduate, 25, single, two years training in distribution department and power plants of large public utility. Desires position with a utility or manufacturing company of moderate size located in South or West in power sales or sales engineering. C-3565.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED SEPTEMBER 19, 1927

AEMMER, FREDERICK, 49 Hemenway St., Boston, Mass.

ANDERSON, HERBERT O., Sales Engineer, Rockbestos Products Corp., 265 Nicoll St., New Haven, Conn.

BARRATT, SIDNEY EDGAR, Production Engineer, Metropolitan-Vickers Australia Pty. Ltd., Auburn, N. S. W., Aust.

BEERBOWER, HAROLD RICHARD, Substation Operator, Consumers Power Co., 524 State St., Saginaw, Mich.

BORCH, HENRIK JONATHAN, Testing Dept., B. M. T., 500 Kent Ave., Brooklyn, N. Y.

BORTON, JESSE THOMAS, Supervisor, Electric Plant Sales, Kohler Co., 32nd & Oxford Sts., Philadelphia, Pa.; res., Glassboro, N. J.

BRUCE, JAMES MALCOLM, Electrical Engineer, Queensland Irrigation Commission, Adelaide St., Brisbane, Queensland, Aust.

BUSBY, ARTHUR H. W., Electrician, Consolidated Mining & Smelting Co., Trail, B. C., Can.

CAMPFIELD, LOUIS MIRAULT, Draftsman, Circuit Breaker Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

COBERG, KNUD CARL, General Electric Co., Bldg. 44, Schenectady, N. Y.

DAMM, GEORGE JOHN, Radio Service, Jebens Hardware Co., 107 Western Ave., Blue Island, Ill.

DAVISON, WILLIAM JOHN M., Davison Engineering Co., Apartado 118, Orizaba, Ver., Mex.

DIVITO, ANTHONY ALBERT, 104 S. 3rd St., Harrison, N. J.

DOLDER, ALEXANDER JULIUS, Stone & Webster, Inc., Boston, Mass.

DUBS, FORD HARVEY, Assistant System Operator, Toledo Edison Co., Acme St., Toledo, Ohio.

EPSTEIN, SOLOMON, Foreman, Repair Dept., A-One Electric Co., 691 Atlantic Ave., Brooklyn, N. Y.

FORTIN, ROMUALD PHILIPPE, District Inspector of Electricity & Gas, Trade & Commerce Dept., Dominion Government, Custom House, Prince William St., St. John, N. B., Can.

GARRATT, JOSEPH F. G., Power Plant Inspection & Installation, E. L. Philips Construction Co., Far Rockaway, N. Y.

GILCREASE, EDWARD EMMET, Tester, Moloney Electric Co., 7th & Hickory Sts., St. Louis, Mo.

GRANT, CHARLES, Inspector Electricity & Gas, Dominion Government, Customs House, St. John, N. B., Can.

GRANT, ELMER GORDON, Chief Electrician, Nashwaak Pulp & Paper Co., Fairville, N. B., Can.

GRAY, JOHN C., President, Gray Electric Co., Inc., 627 Jones St., Detroit, Mich.

GUCKEL, CHARLES HENRY, Laboratory Tester, United Electric Light & Power Co., 514 W. 147th St., New York; res., Elmhurst, N. Y.

*HAMILTON, JULIUS GILLESPIE, Electrical Engineer, Power Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

HANSON, ELBERT TREAT, Electrician, First Class, Stone & Webster, Havre de Grace, Md.; res., Philadelphia, Pa.

HIRSH, DANIEL, Electrical Engineer, Graven & Mayger, 180 N. Michigan Ave., Chicago, Ill.

IYER, P. NATESA, Assistant Engineer, Hydro-electric Surveys, Chepauk, Madras, India.

JAYNE, GEORGE EDMUND, Equipment Engineer's Assistant, Mountain States Tel. & Tel. Co., 800 14th St., Denver, Colo.

JOHNS, GEORGE J., Testing Dept., Union Gas & Electric Co., Cincinnati, Ohio.

JONES, GOMER, Chief Engineer, Hedley Gold Mining Co., Ltd., Hedley, B. C., Can.

KERN, EUGENE AUGUSTIA, Tester, United Electric Light & Power Co., New York, N. Y.

KEY, EDMUND FRANCIS, Electrical Operator, British Columbia Electric Railway Co., Ltd., Lake Buntzen, B. C., Can.

KLIPSCH, PAUL WILBUR, Student Engineer, Testing Dept., General Electric Co., Schenectady, N. Y.

KNIERIEM, PAUL HENRY, Electrical Tester & Inspector, Duquesne Light Co., 620 Braddock Ave., Braddock; res., Pittsburgh, Pa.

KNOWLES, DEWEY DEFOREST, Research Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

KURMAN, NATHAN A., Engineer, Herald Electric Co., Inc., 29 East End Ave., New York, N. Y.

LAFFSA, ARTHUR E., Analysist & Accountant Engineer, Barker & Wheeler, 90 West St., New York, N. Y.

LAKE, ALLAN F., Vice-President, Lake Manufacturing Co., Inc., 1723 Poplar Street, Oakland, Calif.

LAMB, HENRY LINCOLN, Assistant Electrical Engineer, Electricity Dept., Municipal Council, Town Hall, Sydney, N. S. W., Aust.

LEVAN, JAMES D., Research Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

LYNCH, EDWARD, Meter Dept., General Electric Co., West Lynn Works, Lynn, Mass.

MONTVILLE, HAROLD HURST, Electrical Estimator & Engineer, Greer Electrical Construction Co., 125 E. 46th St., New York, N. Y.

MORELAND, LESTER DUANE, Resident Engineer, Phoenix Utility Co.; Florida Power & Light Co. Sarasota, Fla.

NACHMANI, AMMIHUD, 1421 Madison Ave., New York, N. Y.

NUEZEL, ELMER FREDERICK, Assistant Engineer, Columbia Engineering & Management Corp., 314-316 W. 4th St., Cincinnati, Ohio.

PAGET, ALAN LENOX, Student Engineer, General Electric Co., Schenectady, N. Y.

PATON, RUSSELL EDGAR, Laboratory, Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia; res., Fort Washington, Pa.

PEET, HARRY D., JR., Electrical Engineer, Kentucky Electric Development Co., 822 Marion E. Taylor Bldg., Louisville, Ky.

PIERRE, GERALD JOHN, Primary Inspector, Detroit Edison Co., Room 817-2000 Second Ave., Detroit, Mich.

RECK, JOHN ELLSWORTH, Supervisor, Line & Meter Dept., Piqua Dist., Dayton Power & Light Co., Piqua, Ohio.

RICHARDSON, RALPH GORDON, Assistant Electrical Engineer, New Zealand Cooperative Dairy Association, Hamilton; res., Frankton Junction, N. Z.

SANTSCHI, ARTHUR EDWIN, Electrical Heating Engineer, Western Electric Co., Hawthorne Sta., Chicago, Ill.

SIMONDS, KENNETH CLEAVES, Chief Draftsman, Chief Clerk, Western Div. Engg. Office, Florida Power & Light Co., 207 S. Kentucky Ave., Lakeland, Fla.

TERRY, WALTER S., Technical Employee, Long Lines Dept., American Tel. & Tel. Co., 15 Dey St., New York, N. Y.

TRACY, EDWIN S., JR., President, Electrical Engineering Co., Inc., 42 Aberdeen Place, St. Louis, Mo. and Dade City, Fla.

WALDHORST, FRANK, Greenridge Court, White Plains, N. Y.

WEATHERWAX, OLUSTEE KENNETH, Sales Engineer, Pierce Electric Co., 418 N. W. 6th St., Miami, Fla.

WERNER, FRANK, Tester, Moloney Electric Co., 7th & Hickory Sts., St. Louis, Mo.

WHITE, ROBERT M., Experimental Engineer, Sperry Gyroscope Co., Manhattan Bridge Plaza, Brooklyn, N. Y.

WUNDERLICH, NORMAN E., Chief Engineer, Neutrowound Radio Mfg. Co., Homewood; res., Chicago, Ill.

YAMAMOTO, KENKICHI, In charge of Underground Cable, Nippon Denryoku K. K., 1 Sozecho Kita-Ku, Osaka, Japan.

*ZUCKER, MYRON, Electrical Engineer, General Electric Co., Room 620, Bldg. 37, Schenectady, N. Y.
Total 62.
*Formerly enrolled students.

ASSOCIATES REELECTED SEPTEMBER 19, 1927

ANTON, GEORGE, Instructor, Fall River Technical High School, Fall River, Mass.

BISDEE, COLIN E., Asst. Engineer, Hydro-electric Dept., Tasmania, Aust.

OGDEN, PHILIP L., Asst. Engineer, Public Service Co. of No. Illinois, Room 1335, 72 W. Adams St., Chicago, Ill.

YEAGER, WILLIAM FRANKLIN, Consulting Engineer, Day & Zimmermann Eng. & Cons. Co., 1600 Walnut St., Philadelphia, Pa.

MEMBERS ELECTED SEPTEMBER 19, 1927

ATTWOOD, FREDERIC, European Engineer & General European Representative, Ohio Brass Co., Mansfield, Ohio; for mail, 18 Rue de Tilsitt, Paris, France.

FITZGERALD, ALAN STEWART, Engineer, Radio Engg. Dept., General Electric Co., Schenectady, N. Y.

GALLEGO, ALEJANDRO, Mechanical Engineer, Obras Sanitarias de la Nacion, Calle Charcas 1840, Buenos Aires, Arg. Rep., So. Amer.

TRANSFERRED TO GRADE OF FELLOW SEPTEMBER 19, 1927

BARNES, JAMES P., President, Louisville Railway Co., Louisville, Ky.

MAHAN, JAMES S., Electrical and Fire Prevention Engineer, Western Actuarial Bureau, Chicago, Ill.

TEMPLIN, JOHN R., Consulting Electrical Engineer, Christchurch, N. Z.

TRANSFERRED TO GRADE OF MEMBER SEPTEMBER 19, 1927

BINNS, ARTHUR P., Electrical Engineer, Hydro-electric Department, Hobart, Tasmania.

HANCOCK, ROBERT E., Civil Engineer Corps, U. S. Navy, U. S. Naval Station, Cavite, P. I.

PARROTT, REGINALD G., Manager for South America (Except Brazil), Metropolitan Vickers Electrical Export Co., Ltd., Buenos Aires, Argentina, S. A.

SERVOS, FREDERICK M., Chief Electrical Engineer, Rio de Janeiro Tramway Light & Power Co. Ltd., Rio de Janeiro, Brazil, S. A.

SIMPSON, SIDNEY, Consulting Engineer, Messrs. Thomas Cook & Son, Ltd., Hornby Rd., Bombay, India.

RECOMMENDED FOR TRANSFER

The Board of Examiners, under date of September 14, 1927, recommended the following member for transfer to the grade of membership indicated. Any objection to this transfer should be filed at once with the National Secretary.

To Grade of Member

WISE, JOHN S., Jr., Operating Manager, Pennsylvania Power & Light Co., Allentown, Pa.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before October 31, 1927.

Albert, C., Electrical Testing Laboratories, New York, N. Y.
Bakker, J. B., Great Western Power Co., Oakland, Calif.
Baldwin, B. W., Pacific States Electric Co., Seattle, Wash.
(Applicant for re-election.)
Barton, C. G., Ramapo Ajax Corp., Hillburn, N. Y.
Bessey, C. E., Ratheon Mfg. Co., Cambridge, Mass.
Betz, P. L., Consolidated Gas, Elec. Light & Power Co. of Baltimore, Baltimore, Md.
Biche, L. L., (Member), General Electric Co., Pittsfield, Mass.
Brett, R. T., Contractor Dealer, Akron, Ohio
Bryan, D. N., Oregon Short Line Railroad Co., Porcatello, Idaho
Byrns, W. J., with C. W. Greene, 1463 Broadway, New York, N. Y.
Christen, A. A., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Craft, J. G., Consolidated Mining & Smelting Co., Trail, B. C., Can.
Dettmer, A. W., Commonwealth Edison Co., Chicago, Ill.
Donovan, G. M., Canadian General Electric Co., Ltd., Toronto, Ont., Can.
Edens, J. H., Western Electric Co., Inc., New York, N. Y.
Farrell, J. B., Toronto Hydro Electric System, Toronto, Ont., Can.
Gailey, H. M., Curlett & Beelman, Los Angeles, Calif.
Garland, Raymond G., Illinois Glass Co., Gas City, Ind.
Halfvarson, G. A., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Harker, D. C., Westinghouse Elec. & Mfg. Co. San Francisco, Calif.
Helfman, S. J., Duquesne Light Co., Pittsburgh, Pa.
Hind, R. F., New York Central Railroad, New York, N. Y.
Kirkendall, W. E., Los Angeles Railway, Los Angeles, Calif.
Lynch, F. E., New York Edison Co., New York, N. Y.
Martin, L. D., General Electric Co., St. Louis, Mo.
Morrissey, W. J., New York Edison Co., New York, N. Y.
Nott, L. A., Sangamo Electric Co., San Francisco, Calif.
Olsen, W., American Elevator & Machine Corp., New York, N. Y.
Richardson, H. M., General Electric Co., Schenectady, N. Y.
Riddle, A., B. C. Electric Railway Co., Vancouver, B. C., Can.
Sandstrom, E. H., Pacific Tel. & Tel. Co., San Francisco, Calif.
Smith, H. S., Pacific States Electric Co., Seattle, Wash.
Stainback, R. F., Carolina Power & Light Co., Laurinburg, N. C.
Swanberg, O. A., Wilson-Maeulen Co., Bronx, New York, N. Y.
Teommey, G. H., Jr., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Thomas, H. E., Victor Talking Machine Co., Camden, N. J.
Thomson, B. C., Regina Photo Supply, Ltd., Regina, Sask., Can.
Torok, J. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Vander Schaaf, W. D., Public Service Production Co., Newark, N. J.
Wemple, H. R., Jr., Claude Neon Lights, Inc., New York, N. Y.
Total 40.

Foreign

Griffiths, J. L., (Member), East Indian Railway, Charbagh, Lucknow, V. P., India
Hind, B. S., (Member), Andes Copper Mining Co., Casilla B, via Antofagasta, Chile, S. A.
Monkhouse, W. I., Dept. of Public Works, Brisbane, Queensland, Australia
Patel, K. B., (Member), Great Indian Peninsula Railway, Matunga, Bombay 19, India
Rajah, D. S., Electrical Engineer, Nellikuppam, Madras, India
Rao, K. M., M. & S. M. Railway, Madras, India
Spencer, D. N., Guatemala Gold Dredging Co., Morales, Guatemala, C. A.
Tuck, H. P., The University of Tasmania, Hobart, Tasmania
Total 8.

STUDENTS ENROLLED

Goldsmith, Sidney, University of Cincinnati
Jones, Elton W., University of Maine
Pursell, Roger W., Mass. Institute of Technology
St. Louis, James A., Mass. Institute of Technology
Total 4.

OFFICERS A. I. E. E. 1927-1928

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Charles le Maistre, 28 Victoria St., London, S. W. 1, England.
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E., France.
F. W. Willis, Tata Power Companies, Bombay House, Bombay, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
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(A list of the personnel of Institute committees may be found in the September issue of the Journal.)

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(The Institute is represented on the following bodies; the names of the representatives may be found in the September issue of the Journal.)

American Association for the Advancement of Science, Council
American Bureau of Welding
American Committee on Electrolysis
American Engineering Council
American Engineering Standards Committee
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Committee on Elimination of Fatigue, Society of Industrial Engineers
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Joint Committee on Welded Rail Joints
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National Fire Waste Council
National Research Council, Engineering Division
National Safety Council, Electrical Committee of Engineering Section
The Newcomen Society
Radio Advisory Committee, Bureau of Standards
Society for the Promotion of Engineering Education, Board of Investigation and Coordination
U. S. National Committee of the International Electrotechnical Commission
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Washington, D. C.	M. G. Lloyd	H. E. Bradley, Potomac Elec. Pr. Co., 14th & C Sts., N. W., Washington, D. C.
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Cincinnati, University of, Cincinnati, O	C. W. Taylor	W. C. Osterbrock	W. C. Osterbrock
Clarkson College of Technology, Potsdam, N. Y	H. J. Myrback	W. E. Turnbull	A. R. Powers
Clemson Agricultural College, Clemson College, S. C	L. R. Miller	J. U. Wilson	S. R. Rhodes
Colorado, University of, Boulder, Colo	J. A. Setter	R. D. Palmer	W. C. DuVall
Colorado State Agricultural College, Fort Collins, Colo	Harold Groat	Howard Steinmetz	H. G. Jordan
Cooper Union, New York, N. Y	E. T. Reynolds	Wilfred Henschel	N. L. Towle
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Ohio State University, Columbus, O	A. B. Crawford	L. G. Stewart	F. C. Caldwell
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Washington, University of, Seattle, Wash	Wm. Bolster	Arthur Peterson	G. L. Hoard
Washington and Lee University, Lexington, Va	R. E. Kepler	Bernard Yoepp	R. W. Dickey
West Virginia University, Morgantown, W. Va	I. L. Smith	P. E. Davis	A. H. Forman
Wisconsin, University of, Madison, Wis	John Sargent	Leonard Saari	C. M. Jansky
Worcester Polytechnic Institute, Worcester, Mass	D. A. Calder	C. H. Kauke	H. A. Maxfield
Wyoming, University of, Laramie, Wyoming	John Hicks	Edward Joslin	G. H. Sechrist
Yale University, New Haven, Conn	Wm. W. Parker	J. W. Hinkley	C. F. Scott

Total 95

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Floodlighting.—Bulletin GEA 161-A, 24 pp. Describes floodlighting projectors for buildings and also searchlight and airport lighting. General Electric Company, Schenectady, N. Y.

Insulators.—Catalog B-27, 64 pp. Describes Thomas pin-type insulators. The R. Thomas & Sons Company, East Liverpool, Ohio.

Turbine Generators.—Bulletin 20293, 8 pp. Describes geared turbine generator units, for a-c. and d-c. operation, 75 to 500 kw. Westinghouse Electric & Mfg. Company, East Pittsburgh, Penn.

Commutator Undercutters.—Catalog No. 9. Describes eleven different types of motor driven commutator undercutters and slotters. Martindale Electric Company, 1254 West 4th Street, Cleveland, Ohio.

Motors.—Bulletin 151, 8 pp. Describes the new line of Wagner air-jacketed motors, 1 to 30 h. p. Bulletin 152, 4 pp. Describes Wagner across-the-line squirrel cage motors up to 20 h. p. Wagner Electric Corporation, St. Louis, Mo.

Safety Switches.—Catalog 27, 36 pp. Describes "Bull Dog" safety switches. **Feeder Panelboards.**—Bulletin 130, 16 pp. Describes "Unit-Versal SaftoFuse" power and light distributing feeder panelboards. Bull Dog Electric Products Co., Detroit, Mich.

Controllers.—Bulletin 410, 4 pp. Describes types E-2100 and E-2200 Allen-Bradley controlling rheostats. These are used largely in battery charging applications, but are also widely employed for general purposes. Bulletin 704, 4 pp., describes type J-1552 alternating-current reversing switches. In general, these are used for reversing two- and three-phase motors and may be used for reversing certain types of single-phase motors. Bulletin 709, 4 pp., describes type J-1552 across-the-line starting switches. These are designed for starting small single-phase and polyphase motors. Allen-Bradley Company, 496 Clinton Street, Milwaukee, Wis.

"The Lengthening of Niagara Falls" is the title of an attractive, handsomely illustrated in colors, 32-page booklet issued by the Buffalo, Niagara & Eastern Power Corporation, 600 Electric Building, Buffalo, N. Y. It describes a plan for moderating the force of the waterflow over the Horseshoe Falls, which is considered necessary if the American Falls are to be saved from deterioration. The power development at Niagara Falls is also touched upon in the booklet.

NOTES OF THE INDUSTRY

The Hoosier Engineering Company, erectors of transmission lines, announce the establishment of their general offices at 100 W. Monroe Street, Chicago. Branches are located in New York City and Indianapolis.

The Westburg Engineering Company, Chicago, Illinois, announce that they have been appointed district representatives for the Western Electro-Mechanical Company, Inc., Oakland, California, manufacturers of standard a-c. line current test sets; Knopp multi-range a-c. ammeters; automatic reclosing equipment for oil circuit breakers.

The New Departure Manufacturing Company, Bristol, Conn., announce that the increasing demand for New Departure ball bearings on the Pacific Coast has made it necessary to establish a branch engineering office at San Francisco. Elliott A. Allen has been appointed resident manager, with offices at 1812 Van Ness Avenue, San Francisco. Under this new arrangement the Pacific Coast will be served in an engineering as well as a sales capacity for the New Departure product.

The Wade Engineering Company, Los Angeles, Cal., who handle the products of the Lincoln Electric Company, Cleveland, announce that their northern office has been moved from 69 Webster Street, Oakland, to 533 Market Street, San Francisco. The increased sale of "Linc-Weld" motors and "Stable-Arc" welders has necessitated a much larger stock, and increased space has been found necessary.

The James R. Kearney Corporation, St. Louis, Mo., announce the following recent additions to their sales organization: A. F. Zerbst, in the states of Florida, Georgia, Alabama, North Carolina, South Carolina, and part of Tennessee. Mr. Zerbst was formerly connected with the A. T. & T. of Atlanta, Ga.; general superintendent of the Panhandle Power and Light Co., Borger, Texas; and in the statistical engineering department of the Kansas City Power and Light Company. Oscar Marcusen, in parts of New York, Ohio, and Kentucky. Mr. Marcusen was formerly with the Iowa State Board of Railroad Commissioners, Des Moines, Iowa, in the capacity of assistant electrical engineer. Henry M. Hughes, in parts of Pennsylvania, West Virginia, and Ohio. He was formerly with the Franklin Steel Co., Electrical Service Supplies Co. of Philadelphia, H. C. Fry Glass Co. of Rochester, Pa., and is now identified with his own selling organization, the Continental Sales and Engineering Co., of Pittsburgh. A. W. Marshall, in parts of Kentucky and Indiana. Mr. Marshall has his own organization, located in Louisville, Ky. J. G. Smith, in all of Canada west and north of Port Arthur, with headquarters in Winnepeg, Manitoba. H. C. Fiske has been transferred to the Chicago territory covering parts of Wisconsin, Michigan, Ohio, Illinois, and Indiana. E. J. DeRight is now covering parts of Missouri, Arkansas, Mississippi, Tennessee, Kentucky and Illinois.

Largest Storage Battery Locomotive. The largest storage battery locomotive in the world, weighing 110 tons and capable of hauling a 1500-ton train, has just been purchased by the State Line Generating Company for service in its yards at Hammond, Ind. This locomotive, built by the General Electric and Electric Storage Battery Companies, has all the advantages of an electric locomotive but does not require an overhead trolley or third rail for its power. It is noiseless and smokeless in operation, and can accelerate quicker and move a heavy load much faster than other types of switching locomotives.

Its huge storage battery, weighing 39 tons, the largest ever manufactured for this purpose, will deliver 1000 horse power to the driving motors. This power is equivalent to 1579 six-volt batteries such as used for radio purposes, or is sufficient to crank 1600 automobiles simultaneously. A motor-generator set installed in the cab will permit the charging of the battery from a 2300-volt circuit in the plant.

Warren F. Hubley, president, treasurer and general manager of the American Transformer Company, of Newark, N. J., died suddenly on September 19, at the age of 47.

His service with the American Transformer Company dated from 1901 to the present time, a period of twenty-six years. He was treasurer of the Institute of Radio Engineers for eight years and active in N. E. M. A. work, being Chairman of the Parts Committee and a member of the Standards Committee. He was also a member of the Newark Athletic Club, Newark Country Club, Rotary, Radio Club of America, East Orange Rifle Club, Federated Welfare Committee of the Oranges, the Electrotechnical Society, besides other electrical societies and associations. Mr. Hubley was one of the vestrymen of Christ Church, East Orange, and funeral services were held from the church on Wednesday, September 21, 1927.

A man of sterling character, his talents were devoted ungrudgingly to the electrical field and welfare work for the boys and girls and the needy in the community, as well as active work in all the organizations of which he was a member.